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NASA Conference Publication 3093

NASA/MSFC FY90 Global Scale Atmospheric Processes Research Program Review

Proceedings of a workshop held at
NASA George C. Marshall Space Flight Center
Huntsville, Alabama
August 20–21, 1990

NASA

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National Aeronautics and
Space Administration

Office of Management

Scientific and Technical
Information Division

1990

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TITLE: **Comparison of SSM/I Measurements to Numerically-Simulated Cloud and Precipitation During ERICA**

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SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

Investigations of rainbands embedded within extratropical cyclones have documented a spectrum of linear features with varied characteristic dimensions, preferred development locations with respect to hyperbaroclinic zones, and differing physical growth mechanisms. The largest structures are those which have length scales comparable to the supporting baroclinic wave, and which define the macroscale ascent of air in a system-relative sense. Included in this class of structures would be the warm and cold "conveyor belts" that constitute the main influxes of moisture and heat into baroclinic waves. At the other end of the spectrum are mesoscale bands which vary widely in width from a few kilometers to several tens of kilometers. These features evolve with characteristics thought to be constrained by the environmental shear and the thermodynamic stabilities of the larger airstreams.

Recent increases in computational power and advances in physical parameterizations have made numerical simulations attractive as a complementary means of investigating the dynamics of these moist atmospheric systems. We are currently using a version of the Drexel University LAMPS (Limited Area Mesoscale Prediction System) as a source for internally consistent data sets to diagnose processes in synoptic and mesoscale flows. The objective of this work is to understand the processes determining the morphology and bulk microphysical composition of condensation in baroclinic waves. The LAMPS model is notable in that it carries grid-scale predictive equations not only for water vapor, but also for cloud and precipitation. Recently, the model has been extended to account for ice condensate. This addition, along with other improvements, enables a more physically complete treatment of precipitation initiation and growth.

Our investigations this year have focused essentially on the macroscale organization of cloud and precipitation which occurred during the 4th Intensive Observing Period (IOP-4) of the Experiment for Rapidly Intensifying Cyclones over the Atlantic (ERICA). This experiment, held off the East Coast of the United States and Canada during the winter of 1989, documented several episodes of rapid cyclonic storm development. Also playing a major role as validation and ground truth in these studies are SSM/I (Special Sensor Microwave Imager) retrievals of precipitable water, total liquid water and ice, generated by other MSFC-supported investigations. Model simulations produced to date suggest that, while the large-scale atmospheric dynamics was an essential driving mechanism, the role of condensation was crucial in facilitating the exceptionally rapid spinup of the cyclone and the low surface pressure. A model simulation of the precipitation rate at the time of most rapid storm intensification is shown in the accompanying figure. Heavier precipitation rates in the crescent shaped region are associated with deep convection along the leading edge of a dry intrusion behind the surface low. The majority of precipitation in the stratiform region to the northeast involved the production of ice with deposition from vapor to ice being the dominant process of growth. Some small amount of mixed phase cloudiness was present. Model condensate distributions matched well with SSM/I observations. The

accompanying SSM/I imagery which delineates areas of large (> several hundred micron effective radius) precipitating ice over the ocean suggests that the model has done well in capturing the essential mechanisms responsible for the horizonal distribution of precipitation.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

The next phase of this work will be to compare the model simulations and SSM/I observations to aircraft radar returns and in situ measurements of atmospheric temperature, moisture, wind and microphysics data. This will enable some verification of simulated vertical structure to the LAMPS condensate fields, and also help to interpret more accurately the SSM/I data. During the next year we also anticipate studying the role of ocean surface fluxes of moisture and heat in preconditioning the overlying lower atmosphere prior to storm development. The approach of combining remote observations from space, in situ ground truth measurements, and model simulations should enable a more thorough study of the rapid cyclogenesis process.

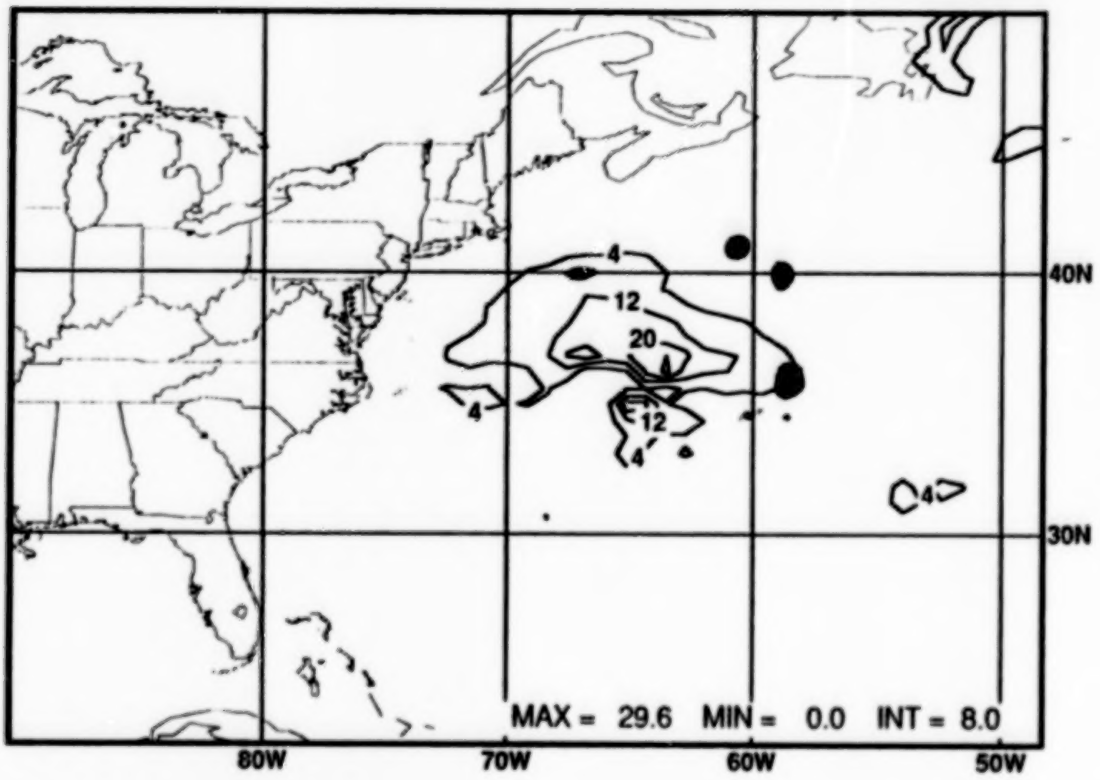
Our experience with regional modeling of moisture patterns supports the concept that these models can be used to study moist processes in an effective manner since they have resolutions comparable to the scales on which precipitation is organized and also to the footprint sizes of passive microwave imagers and sounders. We propose to extend these studies by examining the effect of moisture on regional scale energetics processes. This approach would also involve comparison to climate model integrations to understand how shortcommings in their spatial resolution and parameterized moist physics, which degrade the simulated climate, can be alleviated.

PUBLICATIONS:

Robertson, F.R. and D.J. Perkey, 1990: Comparison of SSM/I measurements to numerically-simulated cloud and precipitation data during ERICA. Preprints, 4th Conference on Mesoscale Processes, American Meteorological Society. June 25-29, 1990 Boulder, Co.

Perkey, D.J., F.R. Robertson, W.M. Lapenta, and C. Cohen, 1990: Comparison of SSM/I measurements to numerically-simulated cloud and precipitation during ERICA. Preprints, 5th Conference on Satellite Meteorology and Oceanograpy, American Meteorological Society, September 3-7, 1990, London, England.

Robertson, F.R., K. Doty and D.J. Perkey, 1990: Numerical Simulation of Cloud and Precipitation Structure during GALE IOP-2. In revision for Mon. Wea. Rev.



(Top) LAMPS simulated Total Precipitation Rate at 1200 UTC 4 January 1989 (12 hours into model integration). Contour interval 8 mm / 10^3 s. (Bottom) SSM/I 85 GHz Polarization Corrected Temperature (a signature of precipitating ice and snowcover) at approximately 0945 GMT 4 January.

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TITLE: Observation Simulation Experiments with Regional Prediction Models

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SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

Research efforts in FY 1990 included studies employing regional scale numerical models as aids in evaluating potential contributions of specific satellite observing systems (current and future) to numerical prediction. One study involves Observing System Simulation Experiments (OSSEs) which mimic operational initialization/forecast cycles but incorporate simulated AMSU radiances as input data. The objective of this and related studies is to anticpate the potential value of data from these satellite systems, and develop applications of remotely sensed data for the benefit of short range forecasts. Techniques are also being used that rely on numerical model-based synthetic satellite radiances to interpret the information content of various types of remotely sensed image and sounding products. With this approach, evolution of simulated channel radiance image features can be directly interpreted in terms of the atmospheric dynamical processes depicted by a model.

Progress is being made in a study using the internal consistency of a regional prediction model to simplify the assessment of forced diabatic heating and moisture intialization in reducing model spinup times. Techniques for model initialization are being examined, with focus on implications for potential applications of remote microwave observations (AMSU and SSM/I) in shortening model spinup time for regional prediction.

1. Satellite OSSE Experiments

A collaborative effort is in progress between MSFC, Drexel University and the University of Wisconsin to simulate and assimilate satellite channel radiances from HIRS, MSU and AMSU. These studies involve radiative transfer calculations on model thermodynamic fields to generate specific channel radiance "measurements" and synthetic radiance imagery with characteristics of future space sensors, and whose patterns can be diagnostically linked with model dynamical processes. These same radiances are also used to study the impact of satellite products retrieved

from these radiances on numerical forecast accuracy. An OSSE approach for studying the impact of HIRS and AMSU radiances and soundings in a numerical prediction cycle has been tested. In these experiments the MSFC-LAMPS regional model served as the nature run and source of simulated HIRS and AMSU radiances for assimilation into Wisconsin's CIMSS regional model. A retrieval algorithm developed by Eyre (1989) for the CIMSS model is used to retrieve thermodynamic profiles from radiances generated from the LAMPS model atmospheric states.

In the evaluation of satellite retrievals it is important to consider not just RMS error statistics of the retrievals, but how much the retrievals contribute to a reduction of error in a model forecast. The OSSE strategy permits a controlled examination of the impact (in this study) of HIRS and AMSU satellite retrievals, and of the assimilation techniques on a model forecast. The quality and potential impact of physically retrieved satellite soundings in an operational forecast setting is largely determined by the quality the first guesses. Both first guess profiles for soundings, and horizontal first guess analysis fields are provided by model output from an earlier forecast cycle. The value of satellite soundings in an assimilation/forecast framework are considered in this study as a function of errors inherent in the retrieval process versus errors implicit in the first guess initial fields and profiles.

A complete OSSE was performed for the Genesis of Atlantic Lows Experiment (GALE) Intensive Observation Period 2 (IOP2) using the LAMPS model as a nature run. A LAMPS forecast state was interpolated to the CIMSS model coordinates to serve as an "perfect" initial state for a control CIMSS run "I". A second CIMSS simulation "II" was performed with the same initial state but including realistic spatial errors corresponding to those that typically derive from the forecast errors in operational prediction models. A third CIMSS simulation "III" additionally included satellite retrievals generated from the nature run in order to observe the degree to which the soundings would correct for initial and forecast errors resulting from the perturbed first guess fields in experiment II.

This methodology will be applied to another case from COHMEX during the next year. Results for the HIRS-AMSU combination are encouraging for one case study, although additional realism needs to be added to the assimilation approach for AMSU radiances and profiles. During the next year, Wisconsin plans to explicity incorporate the effects of cloudwater, rainwater and ice from the LAMPS model in the forward calculation of the AMSU microwave radiances, and also potentially in the retrieval algorithm.

Two companion papers describing this and related simulation work at both MSFC and Wisconsin are being readied for submission to The Bulletin of the American Meteorological Society. Two conference papers have been prepared for presentation at the AMS Fifth Satellite Meteorology and Oceanography Conference this Fall regarding the efforts.

A study is in progress at Wisconsin under this RTOP to simulate the retrieval of cloud properties from AMSU. A paper is being prepared describing a microwave analog to the CO_2 slicing method for determining cloud height using AMSU radiances. Results to date indicate that AMSU channel 19 and 20 can provide accurate cloud heights with RMS errors of 40 to 80 mb over both land and water. As with CO_2 slicing, best results are for high and middle level clouds.

2. Diabatic Initialization Experiments

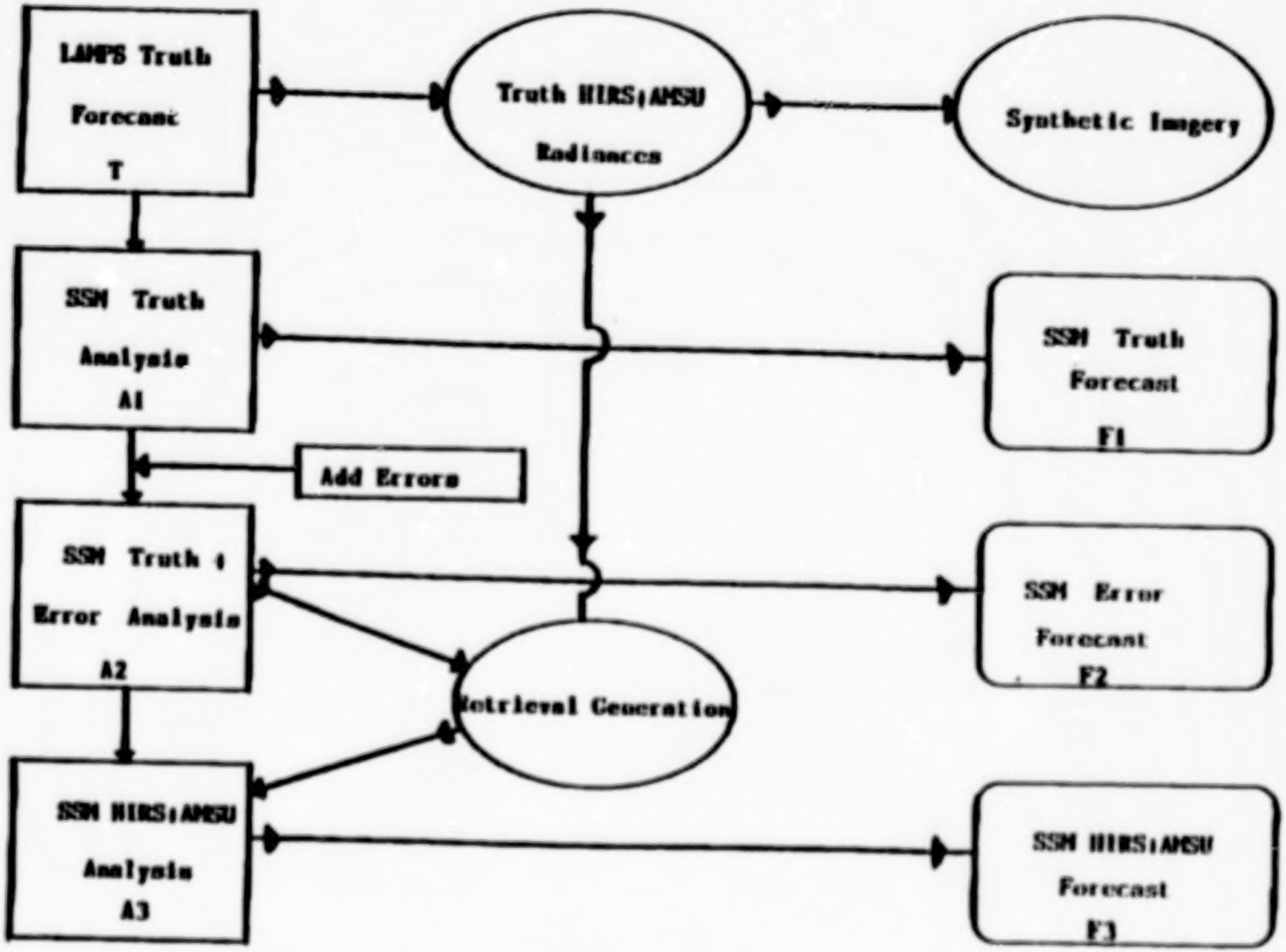
Simulation experiments have been performed with the LAMPS model to elucidate the importance of diabatic heating and meso-scale moisture information in the spinup of precipitation in regional models. A persistent problem in numerical forecasting is an unrealistic delay in the generation of internally consistent, mesoscale divergent wind fields (vertical motion), diabatic heating and precipitation.

This study investigates techniques for reducing model spinup in the LAMPS model through the use mesoscale cloud and precipitation available through space-based microwave senors such as SSM/I to locally modify an otherwise synoptic scale moisture analysis. This study uses a 24 hour LAMPS model simulation for March 6, 1982 as a surrogate (or "true") atmosphere from which is drawn internally consistent meso-beta scale information on clouds, humidity, rainfall and diabatic heating rates. The surrogate atmosphere is sampled to obtain data with an average spacing of 500 km that are then objectively analyzed to provide a synoptic scale atmospheric base state for the remaining model simulations. Experiments based on these synoptic-scale states employ various combinations of forced insertion of true diabatic heating rate fields, replacement of synoptic scale moisture distributions with the true distributions, or enhancement of the synoptic scale moisture distributions based on precipitation and clouds from the "true" atmosphere. The objective of these experiments is to determine which if any of the experimental modifications best reproduces the evolution of true atmosphere, and reduces the spinup time for precipitation compared with a simple dry synoptic scale initialization.

The spinup delay common with a synoptic scale initial state is easily reproduced. Results of all experiments suggest that diabatic forcing by itself only has a weakly positive effect on the spinup, but can have a substantial positive impact on longer term precipitation accumulation with respect to the synoptic control case. The total impact of the forced heating alone is sensitive to the length of the forcing.

The most important factor for spinup is the moisture field. An interesting result was that in terms of spinup time, 12 hour precipitation accumulations, and Mean Sea Level Pressure forecasts, experiments initialized with a synoptic scale humidity analysis enhanced only locally (and very simply) in accordance with clouds and precipitation from the surrogate run performed nearly as well as a simulation with the entire moisture analysis perfectly specified from the surrogate run. The implications are that improvements in short term precipitation forecasts are possible with information only on the horizontal distribution and height of precipitating columns as could be provided from space based microwave sensors.

A paper on the methodologies and results is being prepared. Another case (from ERICA) is being readied to further examine the extent to which the above results study are case dependent.


LAMPS Truth
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Truth HIRS/AMSU
Radiances
Synthetic Imagery
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A1
SSM Truth
Forecast
F1
Add Errors
SSM Truth +
Error Analysis
A2
SSM Error
Forecast
F2
Retrieval Generation
SSM HIRS/AMSU
Analysis
A3
SSM HIRS/AMSU
Forecast
F3

South Pacific Convergence Zone and Global-Scale Circulations: NAS8-37127

Dayton G. Vincent, Purdue University: Principal Investigator
Franklin "Pete" Robertson, MSFC/NASA: Scientific Collaborator

A. Significant Accomplishments (June 1989 - August 1990)

It is the feeling among our research group that the past year was our most exciting and productive one since our association with NASA began in 1983. This can be attributed to three factors. First, Dr. Vincent spent the period, 1 April - 14 November 1989 on research and sabbatical leave at the Institute for Oceanography in Kiel, West Germany (six weeks) and at the Institute for Geophysics and Meteorology in Cologne, West Germany (six months). This provided him with the opportunity to conduct full time research, primarily on our NASA objectives, and to interact with several German scientists and graduate students. Second, the personnel (i.e., graduate students) in our research group collectively have been the best that Dr. Vincent has had the opportunity to work with and supervise. These students are: Jim Hurrell (expected to complete Ph.D. degree in August 1990), Perry Ramsey (Ph.D. student), Keith North (Captain, USAF, completed M.S. degree in May 1990), and Ken-Chung Ko (expected to complete M.S. degree in August 1990). Third, thanks to the hard work and persistence of Jim Hurrell, together with very valuable assistance from personnel at GLA/NASA and the Purdue University Computer Center (PUCC), the GLA General Circulation Model (GCM) was ported successfully to PUCC and is running on the CYBER 205. This is becoming an integral part of our research program and will play an important role in our future plans. An itemized summary of our significant accomplishments is now given.

1. Dr. Vincent presented two papers (one by Pedigo and Vincent, the other by Hurrell and Vincent) at the International Association for Meteorology and Atmospheric Physics (IAMAP) symposium in Reading, England in August 1989.

2. Dr. Robertson, MSFC/NASA, visited Dr. Vincent at the University of Cologne in August 1989 and presented an invited seminar there.

3. Dr. Vincent presented an invited seminar at the Royal Institute of Meteorology for Belgium in Brussels on 6 October 1989.

4. Dr. Vincent presented an invited seminar at a joint meeting of the Institute for Geophysics and Meteorology and German Weather Service in Cologne on 26 October 1989.

5. Three manuscripts were accepted for publication in refereed journals and are listed in section D below.

6. Three additional manuscripts were submitted for publication in the Journal of Climate and are currently in the review process. These are: (a) "Intraseasonal Oscillation of Convective Activity in the Tropical Southern Hemisphere from May 1984 - April 1986" by Vincent and his German colleagues, Sperling, Fink, Zube and Speth; (b) "Precipitation Rate Computations in the Tropics by the Global Heat Budget Technique from June 1984 - May 1987" by North and Vincent; and (c) "On the Maintenance of Short-Term Subtropical Wind Maxima in the Southern Hemisphere during SOP-1, FGGE", by Hurrell and Vincent.

B. Focus of Current Research

Our current research is focused on four topics. First, Jim Hurrell is using the GLA GCM for a series of experiments to examine the relationship between tropical heating and subtropical westerly wind maxima. When this task is completed, we plan to submit the work for publication. Second, Ken-Chung Ko is finishing his M.S. thesis on "Barotropic and Baroclinic Energy Mechanisms Associated with Summertime Subtropical Wind Maxima in the Southern Hemisphere", and we plan to submit it for publication in the near future. Third, Dr. Vincent is using two years of ECMWF data and, together with his Germany colleagues (see A-6), is investigating tropical/extratropical interactions in the Southern Hemisphere summer circulation. We are focusing on the importance of the 30-60 day tropical oscillation as a cause of enhancing the subtropical westerly winds. Finally, Dr. Vincent is working with an undergraduate Honors student, Rob Velasco, whose B.S. thesis research focuses on a study of precipitation efficiency in the tropics. He has been comparing mean monthly distributions of precipitation over a three-year period (Keith North's work alluded to in A-6) to precipitable water and moisture convergence.

C. Plans for Next Year

In August 1990 we start a new research grant. Jim Hurrell and Keith North will have departed our program after completing their degrees, and will be sorely missed. However, we will have three continuing students: Perry Ramsey, Ken-Chung Ko (who will begin Ph.D. work) and Rob Velasco. In addition, a new Ph.D. student, Mark Bourassa, will join our research group in August. As mentioned in section B, manuscripts of the research by Messrs. Hurrell and Ko will be prepared to submit for publication. Also, we plan to submit a manuscript on the research being conducted by Dr. Vincent and his scientific collaborators in Germany (also noted in section B). Perry Ramsey will be taking his Ph.D. Preliminary Examination and Rob Velasco should complete his B.S. Honors research. We plan to make further applications of the GLA GCM, especially with regard to Mr. Ramsey's research on tropical convection and precipitation using ISCCP and other data. Finally, our plans for the coming year include a trip by Mr. Ramsey to present a paper at the Fifth Conference on Satellite Meteorology and Oceanography to be held at London, England in September 1990. Also, Dr. Vincent plans to attend the ECMWF Workshop on "Tropical/Extratropical Interactions of Low-Frequency Oscillations", at Reading, England in September 1990. In addition, we plan to present papers at the "Seventh AMS Symposium on Meteorological Observations and Instrumentation" in New Orleans in January 1991 and at the "Nineteenth Conference on Hurricanes and Tropical Meteorology" in Miami in March 1991.

D. Refereed Publications (June 1989 - August 1990)

1. Robertson, F.R., D.G. Vincent and D.M. Kann, 1989: The role of diabatic heating in maintaining the upper-tropospheric baroclinic zone in the South Pacific. Quart J. Roy. Meteor. Soc., 115, 1253-1271.

2. Pedigo, C.B. and D.G. Vincent, 1990: Tropical precipitation rates during SOP-1, FGGE, estimated from heat and moisture budgets. Mon. Wea. Rev., 118, 542-557.

3. Hurrell, J.W. and D.G. Vincent, 1990: Relationship between tropical heating and subtropical westerly maxima in the Southern Hemisphere during SOP-1, FGGE. J. Clim. (to appear in the June issue).

Research on Diabatic Initialization

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The current four-dimensional meteorological data assimilation schemes employed at forecasting centers are designed to analyze the mass (pressure and temperature) and rotational wind fields accurately, primarily in the middle to higher latitudes. They are deficient in the tropics and in the analysis of irrotational wind and moisture fields. The number of radiosonde water vapor observations is too small to influence the first-guess field of water vapor. The magnitude of irrotational wind component is on the order of observational errors of horizontal wind. Thus, the analyzed irrotational wind and water vapor fields are basically the products of data assimilation models.

The objective of this research project is to contribute to improvement in the synoptic analyses in the tropics for numerical weather prediction and climate research. In addition to a prediction model, four dimensional data assimilation systems have two principal components. One is objective analysis and the other is initialization. Various methods of objective analysis are designed primarily to analyze the mass and rotational wind fields. Methods of initialization are developed to obtain the irrotational wind and its associated vertical velocity field which are balanced with the mass field and free from meteorological noise.

There are essentially three approaches to the problem of initialization: quasi-geostrophic theory, bounded derivative method and nonlinear normal mode method. In the midlatitudes, these approaches generally produce satisfactory results even without diabatic effects for large-scale motions. In the tropics, the situation is quite different from that in the midlatitudes. Because of a small magnitude of the Coriolis parameter and a weak horizontal temperature gradient in the tropics, any method of initialization must incorporate diabatic effects. In fact, we can even say that understanding the problem of *diabatic initialization* is the key to improving the analysis and weather forecasting in the tropics.

[1] The National Center for Atmospheric Research is sponsored by the National Science Foundation.

Research accomplishments over the period of July 1989 – June 1990

Although this project did not formally start until January 1990, we include the results of our preliminary work, carried out under the NCAR core program.

Estimation of the uncertainty of daily synoptic analyses

In order to learn where weakness exists in the present objective analysis procedures, in terms of large disagreement between various analyses, Akira Kasahara and Arthur P. Mizzi conducted the intercomparisons of three different FGGE Level IIIb analysis datasets, the *original* ECMWF (European Centre for Medium Range Weather Forecasts), *reanalysis* ECMWF and *reanalysis* NMC (National Meteorological Center, Washington, D.C.). We examined the daily values of large-scale vorticity ζ, divergence δ, temperature T, static stability Γ, vertical motion ω, and diabatic heating rates Q/C_p during the period of 26 January to 11 February, 1979. In addition to the intercomparison statistics which describe systematic differences, spatial coherence and quantitative agreement, equivalent blackbody temperatures observed by the TIROS-N are used to estimate the relative accuracy of vertical motion and diabatic heating rates in the tropics. They have focussed on the following questions: (1) how data agreement changes depending on the scale of motion, considered at spherical harmonic truncations triangular 13 (T13) and 42 (T42); (2) which aspects of analyses are improved by ECMWF and NMC; (3) which aspects of analysis are still considered unsatisfactory; and (4) what further improvement can be made in the analyses. One piece of good news is that the agreement of vorticity at T13 is excellent and that at T42 is still good, indicating the FGGE has succeeded in describing the quasi-rotational state of the atmosphere, even in the tropics. The bad news is that the agreement of divergence at T42 is poor and, similarly, the vertical motion has the least agreement, indicating the need of further improvement in describing the tropical irrotational circulations.

Solution to the spin-up problem of precipitation forecasts

One deficiency with tropical weather forecasts is that numerical models are incapable of producing realistic tropical precipitation rates at the beginning of the model run. This is known as the 'spin-up' problem and is caused, in part, by shortcomings in the initial specification of divergence, moisture and temperature. Diabatic initialization successfully suppresses inertial-gravity waves but it cannot ameliorate the spin-up problem because: (1) The diabatic information is inadequate for tropical initialization. (2) There is no initialization of the moisture field. (3) There is no initialization of the cumulus parameterization scheme. Kasahara and Mizzi, in collaboration with Leo Donner (University of Chicago), made progress in coming to grips with this spin-up problem. They have developed a tropical initialization procedure to augment current diabatic nonlinear normal

mode initialization (NNMI) schemes. This procedure attempts to initialize cumulus convection in the tropics and consequently reduce the severity of the spin-up problem; *i.e.*, after initialization the precipitation rates vary realistically with respect to time and space throughout the forecast period. This procedure only adjusts initial fields in the tropics since diabatic NNMI is appropriate for the midlatitudes.

Studies on the relationships between the mass and wind fields and diabatic heating

During the past six years there has been much confusion regarding the utility of diabatic NNMI and other NNMI procedures. Taking advantage of a one-year visit to the Naval Environmental Prediction Research Facility (NEPRF) under the UCAR/NEPRF visiting scientist program, Ronald Errico (1989c) has prepared a technical note entitled *Theory and Application of Normal Mode Initialization.* This report is intended for use in graduate studies and includes extensive sections on why NNMI-type balances exist in models and why the NNMI formalism is useful for describing balance.

Errico (1990) has also performed an extensive analysis of dynamic balance in both the CCM (NCAR Community Climate Model) and the Pennsylvania State University/NCAR Mesoscale Model Version 4 (MM4). To the degree that their physical processes are realistic, the balances which the models establish in their equilibrium states are similar to real atmospheric balances. Therefore, the analyses of these simulated data are useful for determining NNMI implementation strategies. Errico's investigation has focussed on three topics: examination of the temporal characteristics of diabatic heating projected on model gravity waves; determination of the degrees to which individual gravity modes satisfied first order and higher order, diabatic NNMI balance conditions; and an examination of balance on the mesoscale. Results indicate that existing balances are adiabatic and that the degree of balance is more a function of vertical scale rather than horizontal scale.

Focus of current research

Kasahara and Mizzi are preparing a manuscript entitled "Estimates of global analysis differences in daily values produced by two operational centers" for submission to *Mon. Weather Rev.* The paper points out the need of a revolutionary idea for improvement in analyzing the tropical circulations which are diabatically driven.

Kasahara, Mizzi and Donner are preparing a talk entitled "Impact of cumulus initialization upon the spin-up of precipitation forecasts in the tropics" to present at the WMO International Symposium on Assimilation of Observations in Meteorology and Oceanography, to be held at Clermont-Ferrand, France, 9–13 July 1990. A manuscript of the same title is also being prepared for publication to *Mon. Weather Rev.*

Plans for next year

Improvement in the analyses of vertical velocity and water vapor fields in the tropics

We plan to apply the findings from our solution to the precipitation spin-up problem to incorporate into the analyses of vertical velocity and water vapor fields, particularly in the tropics. As we mentioned, a revolutionary idea is needed to improve the analyses of irrotational wind and water vapor. In fact, it has been noted that now satellite temperature and humidity soundings (SATEMs) are no longer giving significant impact on analysis and forecasts in the northern hemisphere, due primarily to large errors of SATEM data and to improvement in the dynamical models used for data assimilation. We plan to use satellite radiometric imagery data, which have not been incorporated in operational analysis systems, to identify convective activity in the tropics and as proxy data for the total convective heating rates. We also need the vertically integrated total precipitable water as observed, for example, by Special Sensor Microwave/Imager (SSM/I). In this respect, we plan to cooperate closely with Pete Robertson, MSFC.

Investigation of the role of diabatic heating in the dynamical balance of the atmosphere

There are several outstanding issues related to the problem of nonlinear normal mode initialization (NNMI), particularly in its application to the tropical circulations. Because the tropical circulations are influenced by a smaller magnitude of the Coriolis parameter f and a larger magnitude of the Rossby parameter β, in addition to relatively strong diabatic effects, the question of the dynamical balance between the mass and wind fields in the tropics has been difficult to answer. The NNMI methodology has been very helpful in this connection, but because of its handling of spectral space variables understanding of the balance state has been rather difficult. Another hurdle exists in understanding the role of diabatic heating effects in describing the dynamical balance of the tropical circulations. Because the tropical circulations are characterized by small equivalent depths, the natural frequencies of normal modes representing the tropical motions are relatively small and it is difficult to distinguish between meteorologically significant motions, sometime referred to as oscillations of the second kind (such as Rossby waves) and inertia-gravity motions, often referred to as meteorological noise. We will investigate the role of diabatic heating in the dynamical balance of the tropical atmosphere through various avenues of model research. For example, we will revisit the question of the relationship between the NNMI and the bounded derivative method.

List of Publications

Errico, R. M., 1989a: The forcing of gravitational normal modes by convective heating. *Mon. Weather Rev.*, **117**, 2734–2752.

Errico, R. M., 1989b: The degree of Machenhauer balance in a climate model. *Mon. Weather Rev.*, **117**, 2723–2733.

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Planetary Circulations in the Presence of Transient and Self-Induced Heating

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Progress: The linearized global primitive equation model of Salby and Garcia (1987) has been modified to study tropospheric circulations and their interaction with tropical convection. The vertical resolution has been increased to approximately 1.5 km, with the effective vertical domain extending to approximately 40 km (higher altitudes in the calculation are used to ensure the radiation upper boundary condition is satisfied). A formal wave CISK parametrization has been introduced. That parameterization allows low-frequency disturbances to interact with convection by organizing surface moisture. Boundary layer friction has two important effects in these calculations: (i) It exaggerates surface convergence near the equator by driving the flow out of geostrophic balance. (ii) It introduces a phase shift between the convergence pattern and the circulation, which drives the heating out of quadrature with the temperature field and allows a positive feedback to take place.

The observational complement of this theoretical work involves Global Cloud Imagery (GCI) composited from six satellites in ISCCP which were simultaneously observing the Earth's cloud field. Having global coverage, horizontal resolution of half a degree, and produced *synoptically* every 3 hours, the GCI affords an unprecedented view of global convection. A full year (1983–1984) of GCI has now been succesfully created. Among other phenomena, that imagery reveals a regular progression of easterly waves in the convective pattern of the western Pacific. Those disturbances have odd symmetry about the equator and organize convection into a pattern with similar symmetry. In time-mean maps of cloud cover, these propagating disturbances produce a "split ITCZ" in the western Pacific.

Upcoming Research: Global calculations will be performed to investigate how disturbances to the tropical circulation interact with the convective field. The efficiency which disturbances organize convection is being examined for different space scales and time scales and for its relationship to surface friction and the moisture convergence pattern. Low-frequency convective variability, such as the 40–50 day oscillation, and distinct convective behavior such as the easterly disturbances revealed in the GCI are particular focuses of this work.

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STRATIFORM CLOUDS AND THEIR INTERACTION WITH ATMOSPHERIC MOTION

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During 1989 and 1990, we have seen the publication of two papers and the submission of a third for review on work supported primarily by the previous contract, NAS8-36150; the delivery of an invited talk at the SIAM Conference on Dynamical Systems in Orlando, Florida; and the start of two new projects on the radiative effects of stratocumulus on the large-scale flow. The published papers discuss aspects of stratocumulus circulations (Laufersweiler and Shirer, 1989) and the Hadley to Rossby regime transition in rotating spherical systems (Higgins and Shirer, 1990). The submitted paper (Haack and Shirer, 1990) discusses a new nonlinear model of roll circulations that are forced both dynamically and thermally. The invited paper by H.N. Shirer and R. Wells presented an objective means for determining appropriate truncation levels for low-order models of flows involving two incommensurate periods; this work has application to the Hadley to Rossby transition problem in quasi-geostrophic flows (Moroz and Holmes, 1984). The new projects involve the development of a multi-layered quasi-geostrophic channel model for study of the modulation of the large-scale flow by stratocumulus clouds that typically develop off the coasts of continents. In this model the diabatic forcing in the lowest layer will change in response to the (parameterized) development of extensive fields of stratocumulus clouds. To guide creation of this parameterization scheme, we are producing climatologies of stratocumulus frequency and we will correlate these frequencies with the phasing and amplitude of the large-scale flow pattern. We discuss the above topics in greater detail below.

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR AND FOCUS OF CURRENT RESEARCH

1. A Low-Order Model of Stratocumulus Circulations

Laufersweiler and Shirer (1989) present a new model of stratocumulus circulations. Latent heating effects are parameterized via the no-entrainment assumption, in which upward motions below cloud base are assumed to be dry adiabatic, while upward and downward motions above cloud base are assumed to be moist adiabatic. A stability analysis of the motionless solution shows that there is a preferred mode for which a horizontal wavenumber selection criterion leads to activation of two additional latent heating terms in the moist spectral model. Examination of the resulting convective solutions reveals that the associated patterns are asymmetric: the downdrafts are horizontally narrower and more intense than the updrafts. Evidence that such circulation patterns characterize marine stratocumulus-topped boundary layers has been given by Nicholls (1988). We will use the results from this model and two new ones under development to guide our study of stratocumulus cloud interactions with the large-scale flow.

2. Transitions from Hadley to Rossby Flows

A highly idealized, nonlinear, vertically continuous, rotating, spherical model of global-scale flow is investigated by Higgins and Shirer (1990) to study the transitions from two-dimensional steady Hadley flows to three-dimensional, temporally periodic Rossby flows. Although this subject has been thoroughly covered in channel and cylindrical systems, it has not been addressed very much in spherical ones. The forcing values for the Hadley to Rossby

transition are found to be satisfactorily approximated by the low-order system and agree well with those given by the higher resolution model of Henderson (1982). The most significant transitional behavior that differed from that seen in rotating annuli is that the upper Hadley transition curve is not found in the rotating spherical one. This result agrees with that of Henderson (1982) as well as with that of Miller and Fehribach (1990). In addition, they show that the heating rates for the regime transition curves are realistic only when an effective eddy viscosity, whose use was originally proposed by Dutton (1982), is used to represent the sub-Hadley scale dissipation rates. These ideas will be applied in the analysis performed during our current study.

3. Dynamically and Thermally Forced Roll Vortices

Boundary layer rolls can draw their energy from both the background wind shear and surface heat fluxes. With NASA support we have been developing a series of models (Shirer, 1980, 1986; Stensrud and Shirer, 1988) of these roll circulations; the fourth in the series (Haack and Shirer, 1990) is the first to combine both the dynamic and the thermal mechanisms into one model in order to obtain a more complete description of the possible mode transitions. Three types of modes are found, two dynamic and one thermal. The most significant nonlinear effect that they identify involves the modifications of the background wind and temperature profiles by the rolls. The rolls transport heat vertically so as to bring the boundary layer toward neutral stratification, while momentum is transported vertically so as to add constant shear ($\partial U/\partial z = k$) to the background cross-roll wind profile U(z). Such shear must be removed from observed wind profiles before they can be used to study the dynamical forcing of the roll modes. The manuscript is currently being revised for resubmission this fall.

4. Transitions to Quasi-Periodic Flows

Transitions within the Rossby regime are characterized by vacillation involving flows of two different horizontal wavenumbers. These vacillating flows are found for parameter values near the curves bounding the regions of single-wavenumber, propagating Rossby waves. Moroz and Holmes (1984) explain the onset of this vacillatory behavior as a bifurcation from a temporally periodic Rossby wave to a quasi-periodic one. Such bifurcations can be identified by analysis of the stability of the steady Hadley solution and the identification of double Hopf bifurcation points from which two different temporally periodic Rossby wave solutions emanate. Choosing an appropriate truncation level for a model capable of capturing this type of bifurcation requires an objective procedure. H.N. Shirer and R. Wells are working on such a procedure, which follows one proposed by Kloeden (1986). Preliminary results based on study of rotating convection were presented by H.N. Shirer in an invited paper delivered at the SIAM Conference on Dynamical Systems in May 1990. In this problem, certain spectral coefficients are found to be crucial for properly describing the branching behavior, while others are much less important. The techniques developed in this study will have eventual application to the choice of truncation level for the quasi-geostrophic channel model that is currently being developed.

5. Stratocumulus Modulated Quasi-Geostrophic Flow

Development of a new multi-layered, three-dimensional, quasi-geostrophic channel model of flow responding to the development of stratocumulus clouds in the lowest layer has begun; this is the project for MS student Barbara J. Kratz. Initially the model will have four layers, one for the boundary layer, two for the troposphere and one for the stratosphere (Fig. 1). In the horizontal, half of the domain will be over a continent and half over an ocean. The three-dimensional quasi-geostrophic potential vorticity equation will be integrated in time in the inner layers to give values of potential vorticity $\nabla_H^2\psi + R\partial^2\psi/\partial z^2$, where ψ is the quasi-geostrophic stream function, z is height, and R is a constant. The thermodynamic equation will be integrated

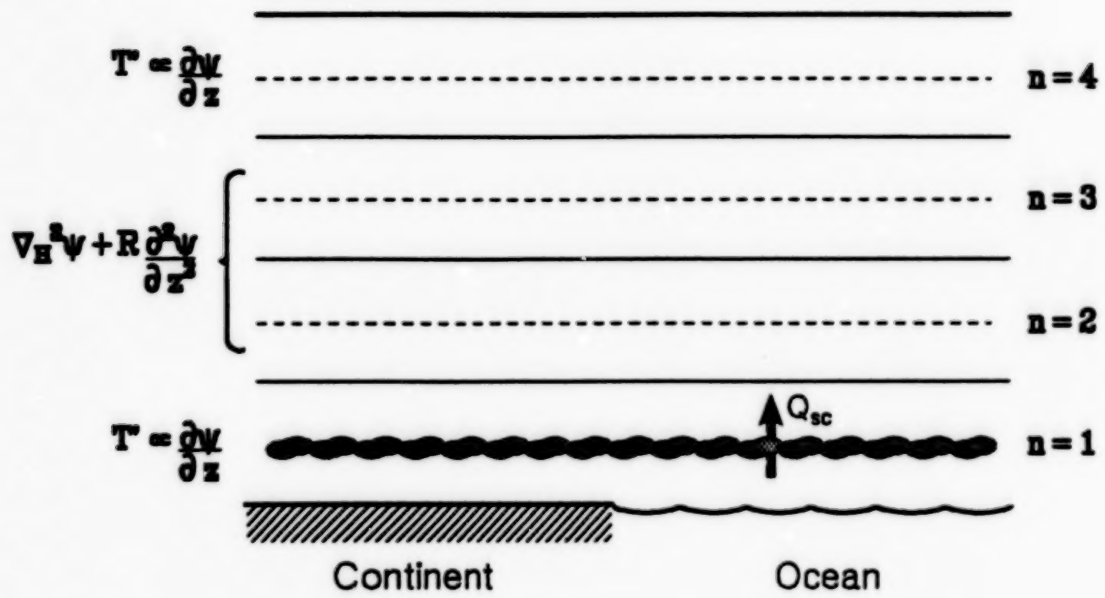

Fig. 1. Cross section of the domain for the model of stratocumulus-modulated quasi-geostrophic flow. The variables that are predicted at each time step before application of the Lindzen and Kuo (1969) scheme are noted by each layer.

in the lowest and highest layers to give values for $\partial\psi/\partial z$. In the bottom layer, this equation will contain a diabatic heating term representing the radiative forcing by a field of stratocumulus clouds. Inclusion of such forcing is motivated by the results of Clark and Schlaak (1988), whose observations demonstrated a link between the index oscillation and the formation of stratocumulus clouds at high latitudes. A truncated spectral expansion based on that used by Vickroy and Dutton (1979) will describe the horizontal variations within all four layers of the new model, while finite differences will represent the vertical coupling between the layers. At each time step, the numerical technique of Lindzen and Kuo (1969) will be utilized to obtain values of ψ in each layer. These values will be found from the values of $\partial\psi/\partial z$ and the interior potential vorticity, which as noted above will be determined from the thermodynamic equation in the bottom and top layers and the potential vorticity equation in the inner layers. The effects of stratocumulus clouds will be parameterized by linking the form of the diabatic forcing term in the lowest layer to the flow pattern given by ψ in all of the layers. In the first year of the grant, we have concentrated on developing the model code for each layer and on preliminary examination and implementation of the vertical coupling routine.

6. Stratocumulus Cloud Climatology

We have begun study of the spatial patterns of stratocumulus cloud frequency for the continental United States and the nearby oceans. An undergraduate student, Charles Pavloski, is developing the necessary numerical codes for accessing the ten-year database of surface and upper air data that we have archived on our departmental computer system. An example of the stratocumulus frequency for April 1990 is given in Fig. 2. Only those stations reporting at least 75% of the time were included in this figure. Maxima along the northeast Atlantic coast, as well as along the northwest and southwest Pacific coasts and the Texas coast, are clearly seen. Minima occur off the southeast Atlantic coast and over the desert southwest of the United States. These climatologies, once correlated with the flow aloft, will provide the basis for the stratocumulus parameterization to be used in the new quasi-geostrophic model.

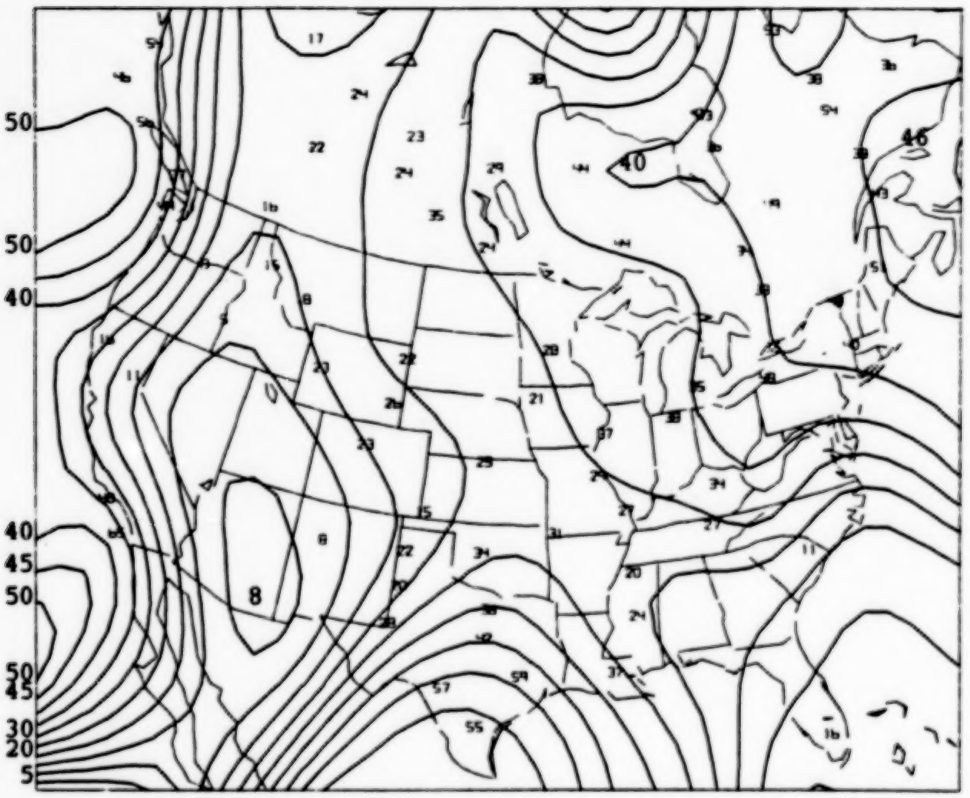

Fig. 2. Observed stratocumulus frequency for April 1990. A station must have reported at least 75% of the time for its data to be included in the analysis.

PLANS FOR NEXT YEAR

1. Stratocumulus Modulated Quasi-Geostrophic Flow

During the next year we will continue developing and testing the numerical algorithms in the new quasi-geostrophic channel model. Once these algorithms work, we will determine the forcing parameter values for the onset of nonlinear Rossby waves and we will determine the horizontal and vertical structures of these waves. Both surface-based and internal diabatic forcing effects will be considered and the results compared with those of previous studies. Based on the results of the stratocumulus climatology project, we will develop a parameterization of the radiative forcing by the stratocumulus. We envision basing this parameterization on the flow pattern near the coast of the continent. For example, in the winter, stratocumulus clouds are expected off the east coast during episodes of low-level cold advection, as evidenced by inspection of satellite pictures. Northwesterly flow aloft is usually associated with cold advection at the surface that produces stratocumulus clouds over the warmer oceans near the east coast of a continent, while the formation of these clouds typically leads to additional radiative cooling of the troposphere from below. Thus, when the model solutions exhibit northwesterly flow, a simple parameterization would produce diabatic cooling in the lowest layer over the western oceanic portion of the domain. Once this parameterization is developed, it will be incorporated into the model and the behavior and sensitivity of the solutions will be examined, with emphasis given to whether or not certain regimes of flow are favored when the stratocumulus modulation is included.

2. Stratocumulus Cloud Climatology

Work on developing the stratocumulus cloud climatology will continue, with emphasis given to associating several-day-long maxima and minima over the oceans with the average flow aloft. First, cases having relatively stationary flow patterns will be identified. For these stationary periods the observed stratocumulus frequencies will be compared with the average phase and amplitude of the height fields aloft. From these results, we will develop a parameterization of the diabatic forcing in the lowest layer by linking the phasing of the height fields on the eastern and western coasts with the observed stratocumulus frequencies. This parameterization will be incorporated into the quasi-geostrophic model and its solutions will be investigated, as discussed above.

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TITLE: **Global Variability of Water Vapor and Condensate from SSM/I**

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SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

In the three years since its launch, the Special Sensor Microwave Imager (SSM/I) has provided the beginnings of a data set crucial to the study of the Earth's global hydrologic cycle. Our investigations with SSM/I have centered largely on two themes: 1) an analysis of the variability in atmospheric moisture as a signature of dynamic and kinematic processes, and 2) development of high quality data sets for determining moisture balance and, eventually, diabatic heating on regional and planetary scales. To date, most of the emphasis has been on the precipitable water field since algorithms for this quantity appear to be the most mature. In addition, we have also begun to work with liquid water, precipitating ice and ocean surface wind stress fields. The retrievals used in these studies are from algorithms developed by Wentz (RSS Tech Rpt. 1989) and Spencer (1988 JTECH).

Storm track analysis

The duty cycle of the SSM/I (nearly complete global sampling every four days) allows the study of variability about means longer than several weeks. Monthly means of SSM/I precipitable water (PWC) and total liquid water (TLW) and their standard deviations have been derived for the purpose of identifying middle latitude storm tracks. We have found that in comparison to ECMWF analyses, the SSM/I generally depicts stronger monthly mean horizontal gradients. The tropical convergence zones, as seen by SSM/I appear somewhat more moist and the subtropical ridges noticeably drier. An implication of this is that for moisture balance calculations which used the SSM/I PWC, sharper, more intense rainfall maxima would result.

2-D Diagnostic assimilation

To analyze the space/time variability of SSM/I variables, a data set with uniform, synoptic sampling is required. Unfortunately, because of the asynoptic nature of sun-synchronous orbits and non-overlapping swaths at tropical latitude this coverage is not available from the raw data. Significant progress has been made in applying Lagrangian methods to interpolate the data into a synoptic format. In studying lag correlation statistics of the SSM/I swath data it is apparent that the propagation (phase vector) of synoptic disturbances is well related to lower tropospheric winds. A simple transport model was developed that uses lower tropospheric winds to horizontally advect water vapor or cloud water. The model uses a nudging term to update the analysis so that at at any (x,y) location the solution agrees exactly with the SSM/I observations. The evolving solution is sampled at regular time intervals to yield synoptic analyses of SSM/I variables. This data set can form the basis of bandpass analyses to isolate synoptic from longer term variability.

4-D Multiphase water analysis

The analysis described above provides a synoptic mapping employing rather minimal adjustment to the SSM/I data. To derive a data set which yields consistent diagnoses of vapor, cloud and

precipitation requires vertical structure as well. A model has been constructed that uses SSM/I observations as a constraint on an evolving 3-dimensional moisture field. The basic formalism for the 4-Dimensional multi-phase water analysis (4-DMPW) is a diagnostic assimilation procedure. In this methodology, wind fields from ECMWF gridded analyses have been used to drive conservation equations for vapor, liquid and ice. These equations, which also use bulk parameterizations of microphysics (e.g. condensation, autoconversion, collection, precipitation evaporation and fallout) are updated, or constrained in such a way that where SSM/I observations are available, the analysis agrees to within measurement accuracy. The qualifier "diagnostic" means that the wind field and temperature are specified from the ECMWF analyses and not predicted by this constrained model.

Our initial investigations suggest that this methodology can provide realistic, 3-dimensional evolving fields of vapor and condensate. The moisture balance and vertical structure of condensate derived by this method makes use of the best moisture field (SSM/I), and is kinematically consistent with global wind fields and simple but fairly realistic bulk microphysics. We have also noted that, as expected, analysis results are sensitive to the quality of the specified vertical motion, and that current analyses of this variable are in need of improvement.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

Results from the 2-D model which provides a synoptic analysis of SSM/I data are being examined to assess the sensitivity to the specification of phase speed from ECMWF wind analyses. We will use these moisture and cloud fields as a basis for bandpass analysis of various scales. We expect the variability of storm tracks location and intensity, as evidenced by SSM/I to be a very useful indicator of low-frequency (intraseasonal) and short-term climate variability.

The studies to date with the 4-D MPW analysis have been exploratory. We will pursue including more sophisticated representations of shallow and deep convection within this diagnostic assimilation framework. We are currently exploring ways of using SSM/I ice and liquid water signatures to alter the ECMWF vertical motion fields.

Many of the analyses refered to here will be available for critiquing the NCAR Community Climate Model in a collaborative effort with the Climate Modeling Section. Some of the TLW fields have already been used in developing and tuning moist physics packages for the next version of the model, CCM2. In addition, we are collaborating with Dr. Akira Kasahara in application of the the SSM/I moisture and inferred vertical motion / divergence patterns to the cumulus initialization problem.

PUBLICATIONS:

Robertson, F. R. and J.R. Christy, 1989: Global analyses of water vapor, cloud and precipitation constrained by SSM/I retrievals. Preprints, Fifth IAMAP Scientific Assembly, 31 July-5 August, 1989 Reading, England.

Robertson, F.R., 1990: Global analyses of water vapor, cloud and precipitation derived from a diagnostic assimilation of SSM/I geophysical retrievals. Preprints, Fifth Conference on Satellite Meteorology and Oceanography, Sept 3-7, 1990, London, England.

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Project Title: Global-Scale, Intraseasonal Fluctuations of Diabatic Forcing of the Atmosphere

Progress:

Fields of diabatic heating rate estimates (H) for 5-day periods have been calculated from ECMWF analyses since 1985 as the residual of the dry thermodynamic equation. Included in these fields are the horizontal and vertical divergences of heat for both mean and eddy statistics. Previous work dealt with 4-day periods, however, with the emphasis in the Global Precipitation Climatology Project for 5-day period totals the change was made to accommodate the GPCP product.

H has long been associated with cold tropical cloud-top temperatures as measured by polar orbiting OLR sensors. Correlations between H and OLR fields on three time scales indicate a moderate amount of agreement. For periods less than 90 days, significant negative correlations are found between H and OLR for 1) tropical and NH midlatitude oceanic areas and 2) for zonal and hemispheric mean values. Positive correlations are seen in NH mean and continental areas of N. Africa, N. America, N. Asia and Antarctica. These latter results reflect seasonal heating and cooling.

Comparisons have been made between H as calculated from the ECMWF analyses and output from the CCM1 T42 simulations. The CCM1 tends to have a more cellular structure with more heating (precipitation) over land versus that observed (ECMWF) over oceans.

Future Work:

Fields of H will continue to be produced from the ECMWF analyses. It is anticipated that by the end of 1992 the ECMWF reanalysis effort will be underway so that consistent maps will be available from 1979 onward. A modeling study is also underway in (no-cost) collaboration with Dr. S.-C. Chen of Scripps. We are analyzing the unique atmospheric forcing which occurred in the NH spring of 1988 over the subtropical Pacific and the resulting flow which may have caused the severe drought in the Central and Eastern US that year. Using known forcing anomalies (from H) we are able to reconstruct the modelled fields to determine the source of the forcing (i.e. surface heating, eddy or mean flow forcing etc.).

Publications:

Christy, J.R., 1990: Diabatic heating rate estimates from ECMWF analyses. J. Geophys. Res., D, accepted for publication.

Conferences:

Christy, J.R., and F.R. Robertson 1990: NCAR CCM1 at MSFC, Validation against satellite layer temperatures and ECMWF analyses. CCM Workshop, 16-20 July 1990, Boulder CO.

Christy, J.R., 1989: Global distribution of diabatic heating rate estimates. Symposium on Role of Clouds in Atmospheric Chemistry and Global Climate. 30 January - 3 February 1989, Anaheim CA, pp. 56-59.

Robertson, F.R., R.W. Spencer and J.R. Christy, 1989: Geophysical parameters from microwave retrievals. Workshop Proceedings. Workshop on the use of Satellite Data in the European Centre for Medium Range Weather Forecasts model. 8-12 May, 1989. Reading UK, pp. 435-451.

Christy, J.R., 1988: Global scale diabatic heating rate distribution and atmospheric mass anomalies. Proceedings of the Thirteenth Annual Climate Diagnostics Workshop. 31 October - 4 November 1988, Cambridge

TITLE: Tropical Pacific Moisture Variability

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RESEARCH OBJECTIVES:

1. To describe synoptic scale variability of moisture over the tropical Pacific Ocean and the systems leading to this variability.
2. To implement satellite analysis procedures to accomplish (1).
3. To incorporate additional satellite information into operational analysis/forecast systems at NMC.

SIGNIFICANT ACCOMPLISHMENTS IN FY-88/89:

JPM spent eight months of FY-88/89 at NMC's Development Division under joint sponsorship of UCAR/NMC/NASA; this leave stretched out funding of the NASA contract with concomitant reduction in effort.

1. Modification of NMC models with satellite data. Composite satellite radiance patterns describe features detectable well before the development of synoptic scale tropical plumes. These typical features were extracted from historical files of TOVS radiance observations for a pair of tropical plumes which developed during January 1989.. Signals were inserted into the NMC operational medium range forecast model and a suite of model integrations were conducted. Many of the 48 h model errors of the historical forecasts were eliminated by the inclusion of more complete satellite observations.

2. Satellite radiance analysis. Three studies progressed:

a. . Fink completed an analysis which blended TOVS moisture channels, OLR observations and ECMWF model analysis to generate fields of total precipitable water comparable to those estimated from SMMR μ-wave observations. This study demonstrated that a 10 y climatology of precipitable water over the oceans is feasible, using available infrared observations (OLR and TOVS) and model analysis (ECMWF, NMC or similar quality). The estimates are sensitive to model quality and the estimating model must be updated with operational model changes.

b. Coe developed a set of tropical plume and ITCZ composites from TOVS observations, and from NMC and ECMWF analyses which had been passed through a radiative transfer model to simulate TOVS radiances. The composites have been completed as well as many statistical diagnostics of individual TOVS channels. Analysis of the computations is commencing.

c. Chung has initiated a study of the differences between TOVS observed vapor structure during ENSO (1983) and non-ENSO (1984) years. Preliminary diagnosis demonstrates gross moisture changes between warm and cold sea surface temperature episodes.

3. Tropical plume mechanisms.

a. Askue constructed a shallow-water model to measure barotropic tropical wave interaction. We hypothesized that tropical plumes, as described by TOVS radiance composites, could result from instabilities associated with wave-wave interaction. Although plume-like wave growth could be induced, instability due to triad interaction or linearized wave-wave interaction is not sufficiently vigorous to explain completely plume evolution.

b. Lee is nearing completion of an energetics study to describe plume behavior and environment in ENSO and non-ENSO years with both ECMWF and NMC analyses. Instability processes are different in the two analyses, although gross environmental behaviors are similar. Important differences are associated with the steady equatorial convection of ENSO events.

FOCUS OF CURRENT RESEARCH AND PLANS FOR FY 90/91:

This year's focus will continue to be the understanding and utilization of satellite radiance data, directed particularly at the moisture fields of synoptic-scale systems, a problem currently not well understood. An additional focus is the modelling and understanding of tropical synoptic scale dynamics, as revealed from the last six years of satellite data analysis.

1. The NMC model diagnosis, Coe's composited radiation simulation, and Lee's energy study will be completed.

2. Chung's study of moisture structure over the Pacific Ocean and its observation and statistical properties will continue throughout the year. More tasks may be initiated if additional Air Force graduate students are identified.

3. Three modelling studies will be initiated, or continued:
   a. A global barotropic model, with a realistic 200 mb basic state will be initialized with typical divergent forcing to trigger tropical plumes.
   b. The same model will be run with ENSO-like basic state to examine tropical plume suppression and Walker circulation dynamics.
   c. The barotropic model will be used as the basis for a baroclinic model to attempt to develop tropical plumes without arbitrary forcing.

PUBLICATIONS (since July 1989):

Refereed:

McGuirk, J.P., and D.J. Ulsh, 1989: Evolution of tropical plumes in VAS water vapor imagery, Mon. Wea. Rev. (To be published, August 1990)

Presentations:

McGuirk, J.P., J.R. Schaefer, D.E.W. Smith and G.A. White, 1990: Effects of satellite observational characteristics of EOF structure, AMS 11th Conf. on Probability and Statistics in Atmospheric Sciences, Monterey CA, October, 1989.

_____, and D.E.W. Smith, 1990: TOVS channel radiances as a "ground truth" for ECMWF analysis, AMS 5th Conf. on Satellite Meteorology and Oceanography, London, September 1990.

_____, 1990: Use of satellite-derived spatial patterns in synoptic-scale numerical forecasts, op. cit.

Theses/ Dissertations:

Askue, C.A., 1989: Barotropic mechanisms associated with tropical plume formation, PhD., 188pp.

[Totaling 7 refereed publications, 31 conference papers, 10 MS. theses, 4 Phd. dissertations under 7 yrs. of NASA sponsorship, commencing April 1983.]

Title: Nonlinear Dynamics of Global Atmospheric and Earth-System Processes

Investigators:

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Significant Accomplishments in the Past Year:

1) Theoretical Studies of Planetary Waves and Low Frequency Atmospheric Variability. During the past year we completed two papers dealing with the dynamical properties of the planetary waves in the atmosphere; both of these studies point to possible sources of the observed systematic errors in numerical weather predictions. In the first of these papers, Ebisuzaki (1990) shows that eastward-tilting, westward-moving waves are a distinctive feature of the mid-latitudes, particularly in winter. One source of these waves is the interaction of baroclinic unstable waves with standing waves forced by the continents and ocean; a failure to model these interactions correctly can be a significant source of long wave error in numerical predictions.

   In the second paper, Pandolfo and Sutera (1990) discuss the effects of the zonal mean wind variability on the energy propogation of a stationary Rossby wave in a barotropic non-divergent atmosphere are studied. It is shown that the random nature of the zonal wind fluctuations do not allow Rossby wave energy to propagate from its energy source. The mechanisms for this effect is strongly dependent on the spatial resolution at which the zonal mean flow is assumed to be known; this suggests that models with too low a latitudinal resolution will allow too much wave energy to propogate from middle latitudes resulting in systematic errors similar to those observed.

2) GCM Studies of the Atmospheric Response to Boundary Conditions Observable by Satellites. A series of GCM sensitivity experiments have been conducted to determine the atmospheric response to significant features of the earth's surface that are measured by systematic satellite observations; these are (i) surface soil moisture (Oglesby and Erickson 1989), (ii) localized sea-surface temperature, over the Gulf of Mexico (Maasch and Oglesby 1990), and (iii) sea ice coverage (Oglesby 1990). In addition, an important sensitivity study for the response of surface air temperature to systematic changes in atmospheric carbon dioxide ranging from 100 to 1000 ppm was completed (Oglesby and Saltzman 1990); the response is found to be nonlinear,

showing greater sensitivity for lower values of CO_2 than for the higher values. It is suggested that changes in CO_2 concentration of a given magnitude (e.g., 100 ppm) play a larger role in the Pleistocene ice age type temperature variations, than in causing global temperature changes due to anthropogenic increases.

3) Dynamical studies of Long-Term Variations of the Global Earth-System. In a series of papers (Maasch and Saltzman 1990, Saltzman and Maasch 1990a,b) we have explored the degree to which the major changes in terrestrial climate and the carbon dioxide concentration associated with the Pleistocene "ice ages" can be accounted for internally by complex nonlinear interactions involving the atmosphere, biosphere, hydrosphere, and cryosphere. In the last of these contributions we show how positive feedbacks in the global carbon cycle, as controlled by the deep ocean state, can provide the instability to drive the major ice age cycle. When additive external forcing (e.g., due to earth-orbital, Milankovitch, radiative variations) is applied, much of the inferred global variations of climate over the past 2 million years, including the "jump" about 900 thousand years ago, can be explained with a relatively small number of adjustable parameters. The consequences of this model for the effects of the anthropogenic CO_2 increase have also been explored (Saltzman and Maasch 1990c), showing that this increase may have displaced the slow-response earth-system to a dynamical domain far from that of the ice-age oscillations prevailing over the last million years.

Focus of Current Research and Plans for Next Year:

We are continuing our studies of the nonlinear dynamics of global weather systems, emphasizing the following specific tasks:

1) Sensitivity analyses of large-scale dynamical models of the atmosphere (i.e., general circulation models i.e., GCM's) to establish the role of satellite-signatures of soil moisture, sea surface temperature, snow cover, and sea ice as crucial boundary conditions determining global weather variability.

2) To complete our study of the bimodality of the planetary wave states, using the dynamical systems approach to construct a low-order theoretical explanation of this phenomenon. This work should have important implications for extended range forecasting of low-frequency oscillations, elucidating the mechanisms for the transitions between the two wave modes.

3) To use the methods of "jump" analysis and "attractor dimension" analysis studied under the previous grant, to examine the long-term satellite records of significant variables (e.g. long wave radiation, and cloud amount), to explore the nature of mode transitions in the atmosphere, and to determine the minimum number of equations needed to

describe the main weather variations with a low-order dynamical system.

4) Where feasible we will continue to explore the applicability of the methods of complex dynamical systems analysis to the study of the global earth-system from an integrative viewpoint involving the roles of geochemical cycling and the interactive behavior of the atmosphere, hydrosphere, and biosphere.

Publications (1989-1990)

1) Maasch, K. A. and B. Saltzman, 1990: A low-order dynamical model of global climatic variability over the full Pleistocene. J. Geophys. Res., 95, 1955-1963.

2) Oglesby, R. J. and E. J. Erickson III, 1989: Soil moisture and the persistence of North American drought. J. Climate, 2, 1362-1380.

3) Oglesby, R. J. and B. Saltzman, 1990: Sensitivity of the equilibrium surface temperature of a GCM to systematic changes in atmospheric carbon dioxide. Geophys. Res. Lett., (in press).

4) Saltzman, B. and K. A. Maasch, 1990a: A first-order global model of late Cenozoic climatic change. Trans. Roy. Soc. Edinburgh, (in press).

Submitted for Publication

1) Ebisuzaki, W., 1990: Vertical tilts of tropospheric waves: observation and theory. J. Atmos. Sci. (submitted).

2) Maasch, K. A. and R. J. Oglesby, 1990: Meltwater cooling of the Gulf of Mexico: GCM implications for climatic conditions at 12 ka. Paleoceanography (submitted).

3) Oglesby, R. J., 1990: The influence of sea ice extent on the Southern Hemisphere oceanic and atmospheric circulation. (abstract, manuscript in preparation).

4) Pandolfo, L. and A. Sutera, 1990: Rossby waves in a fluctuating zonal mean flow. Tellus (submitted).

5) Saltzman, B. and K. A. Maasch, 1990b: A first-order global model of late Cenozoic climatic change II. A simplification of CO_2 dynamics. Climate Dynamics (submitted).

6) Saltzman, B. And K. A. Maasch, 1990c: Possible effects of increased CO_2 on the structural dynamics of climate: implications for ice age cycles. Science (submitted).

LABORATORY AND THEORETICAL MODELS OF PLANETARY-SCALE INSTABILITIES AND WAVES

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Meteorologists and planetary astronomers interested in large-scale planetary and solar circulations recognize the importance of rotation and stratification in determining the character of these flows. In the past it has been impossible to accurately model the effects of sphericity on these motions in the laboratory because of the invariant relationship between the uni-directional terrestrial gravity and the rotation axis of an experiment. We have studied motions of rotating convecting liquids in spherical shells using electrohydrodynamic polarization forces to generate radial gravity, and hence centraly directed buoyancy forces, in the laboratory.

The GFFC (Geophysical Fluid Flow Cell) experiments performed on Spacelab 3 in 1985 have been analysed. Recent efforts at interpretation have led to numerical models of rotating convection with an aim to understand the possible generation of zonal banding on Jupiter and the fate of banana cells in rapidly rotating convection as the heating is made strongly supercritical. In addition, efforts to pose baroclinic wave experiments for future space missions using a modified version of the 1985 instrument have led to theoretical and numerical models of baroclinic instability. Rather surprising properties were discovered, which may be useful in generating rational (rather than artificially truncated) models for nonlinear baroclinic instabilty and baroclinic chaos.

RESEARCH HIGHLIGHTS: June 1989 - June 1990

COLUMNAR CONVECTION

Under conditions of rapid rotation and relatively low differential heating, convection in a spherical shell takes place as columnar "banana cells" wrapped around the annular gap, but with axes oriented along the axis of rotation. These were clearly evident in the GFFC experiments. Because the cells are aligned with the rotation axis, the simplest models for understanding their dynamics can be two-dimensional. There has been much recent effort to understand this type of 2-D convection. For example, Lin Busse and Ghil (GAFD, 45, 1989) use a spectral truncated low-order model to map out speculations about the transition to chaos. Lin (GAFD, 1990, to appear) produced a low order model that generates *strong zonal banding* through the Reynolds stress associated with thermal convection in the presence of shear. This claim, which is offered as a mechanism for the banding on the giant planets, is in much dispute. Such bands were not seen in GFFC, although the parameters were different from those used by Lin. In an effort to resolve this dispute, a very accurate 2-D numerical model with resolution approaching 1024^2, was constructed. This model reproduces the GFFC results qualitatively. When extended to the cases studied by Lin no "double column instability" was found. The zonal flows were relatively weak. Interestingly, the convective cells grouped together in the form of envelope solitons (Brummel et. al, 1990). Additions to the 2-D physics which will possibly lead to a strong zonal acceleration are under study.

Other numerical studies were completed which demonstrate the effects of compressibility and relatively high heat diffusion (typical of planetary and stellar atmospheres) on thermal convection, and on processes that may lead to different classes of turbulence in Boussinesq laboratory convection.

BAROCLINIC FLOWS AND BAROCLINIC CHAOS

Linear instability calculations by Dr. T. Miller at MSFC indicate that the GFFC should exhibit classic baroclinic instability at accessible parameter settings. Of interest are the mechanisms of transition to temporal chaos and the evolution of sptio-temporal chaos. In order to understnad more about such transitions we have conducted high resolution numerical experiments for the physically simplest model of two layer baroclinic instabitity. This model has the advantage that the numerical code is exponentially convergent and can be efficiently run for very long times, enabling the study of chaotic attractors without the often devastating effects of low-order trunction found in many previous studies.

The principal results are:

1) There are a countable infinity of invariant manifolds in spectral space. This means that for a given set of external parameters

that there are potentially an infinity of possible distinct statistical equilibria. In practice most of these are unstable, but numerical studies have shown that for parameters relevant to the atmosphere, at least two and more typically three or four states can be attained a large times depending on the initial conditions.

2) The transition to chaos computed with high resolution (typically 64^2 spectral modes) is abrupt. Low order models predict exotic transition sequences (period doubling sequences, tori fragmentation). The fully resolved model behaves differently, with an imperceptibly small transition layer.

3) The transition to chaos and the nature of turbulent flow is strongly affected by the addition of a small amount of time-dependent seasonal forcing. The dynamic origions of these effects are associated with the periodic forcing causing the system to locally approach homoclinic trajectories of the various invariant spectral manifolds in the system. A theory based on this idea may lead to a better understanding of chaotic baroclinic wave systems.

RESEARCH PLANS

We wish to pursue a better understanding of nonlinear baroclinic flows, which are important in internal climate variability. Baroclinic instability in channels annuli with both rigid (a la GFFC) and slippery meridional walls at fixed latitudes (a la the classical meteorogical theories) will be studied using both low-order and high-resolution numerical models. The emphasis will be on the following questions. What is the nature of the chaotic dynamics? How does it depend on boundary conditions? What is its fractal properties? Can it be represented by a robust low-order description?

For some ranges of external parameters, high resolution models indicate large-scale chaotic baroclinic waves with fractal dimensions of less than 10. The real atmosphere has a higher dimensional attractor, but this includes motions on smaller scales which may be less important for global climate modelling. Two methods of obtaining a robust low-order description will be tried. First, we shall try to obtain the inertial manifold for quasi-geostrophic baroclinic chaos. This manifold represents the inertial component of motion where the dissipative scales are projected or slaved to the low-order motion. The motion on the inertial manifold is much easier to compute than solving the full PDE's using spectral methods that include high enough wavenumbers that the dissipative modes are explicitly calculated.

If there is not a strong dissipative range of scales, or if such scales are very far removed from the energy containing eddies, then the inertial manifold approach may not be effective. Variants on the Proper Orthogonal Decomposition method will be tried. Empirical Orthogonal Functions that capture an optimum amount of energy are one example. Others may be better. Ideally it is not clear that energy optimization will track the flow on a strange attractor. For example, high energy modes may be slaved together. Other possibilities, like

the invariant wavenumber sets found by Cattaneo and Hart (1990) may be useful.

We shall also consider numerically the role of viscous sidewall layers (and possible flow separation) on the transition to chaos. In addition to providing new theories for the transition to chaos in baroclinic instability which will be of major interest in atmospheric and ocean sciences, this work will offer guidelines for scientifically important GFFC experiments with a stable stratification.

Other numerical work will continue study of the narrow annulus columnar convection models, including attempts to construct an analytical theory for the envelope convective solitons observed in our recent computational experiments. Laboratory work will focus on baroclinic annulus waves with non-zonally-symmetric heating (to verify theories about storm tracks), and on baroclinic waves with seasonal forcing (to verify ideas about the pivotal role seasonality can play in baroclinic chaos).

PUBLICATIONS WITH NASA SUPPORT

Brummel, N., Cattaneo, F., and J.E. Hart, "Numerical models of columnar convection", in preparation, 1990.

Cattaneo, F., and J.E. Hart, "Multiple states for quasi-geostrophic baroclinic channel flows", *Geophysical and Astrophysical Fluid Dynamics*, 33 pages, in press 1990.

Cattaneo, F., N.E. Hurlburt and J. Toomre, "Supersonic convection", *Astropohys. J.*, 353, 678-697, 1990.

DeLuca, E.E., J. Werne, R. Rosner and F. Cattaneo, "Numerical simulations of soft and hard turbulence. I. Preliminary results for the two-dimensional convection", *Phys. Rev. Lett.*, in press, 1990.

Hart, J. E., "Experiments on planetary scale instabilities", *Nonlinear Ocean Physics*, ed. A. Osborne, 43 pages, Italian Physical Soc., in press 1990.

Hart, J.E., "Microgravity laboratory simulations of planetary and stellar circulations", *Microgravity Science and Technology*, 3, 15 pages, in press 1990.

Hart, J.E., "Finite amplitude baroclinic instability with periodic forcing", *Physica D*, 39, 239-261, 1989.

Toomre, J., Brummell, N., Cattaneo, F., and N.E. Hurlburt, "Three-dimensional compressible convection at low Prandtl numbers", *Comput. Phys. Comm.*, in press, 1990.

Title: Theoretical and Experimental Studies of Baroclinic Processes

Investigators:

Tim Miller, PI
MSFC, ES42

Fred Leslie, Shih-Hung Chou
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Nathaniel Reynolds (UAH), H.-I. Lu (USRA), Karen Butler (NTI)

Significant Accomplishments in the Past Year:

The fully nonlinear, nonhydrostatic, three-dimensional geophysical fluid flow simulation code, GEOSIM, has been developed, validated, and exercised for several problems. The code is cast in spherical coordinates and is finite difference in the meridional plane (latitude and height) and spectral in the azimuthal. This formulation allows the modeling of a full sphere or any axisymmetric part thereof (i.e., latitudinal walls may be inserted), which permits the use of the code for cylindrical or channel configurations. The code has been validated by comparing with previous numerical results and with experimental observations.

A paper by Miller and Fehribach was accepted and published in the past year which uses the axisymmetric and linear wave options of GEOSIM. This paper studies the onset of baroclinic wave instabilities in the GFFC apparatus. The results of the study show that there is a large region of parameter space which is accessible using the existing hardware which would result in baroclinic wave flow. Interestingly, the results indicate an advantage with the capability to heat the pole rather than the equator; in the equatorially-heated case, centrifugally-induced convection would occur which complicates the dynamics and which is non-Earth-like.

A paper by Miller and Butler has been accepted and is awaiting publication. This work was part of the validation process for GEOSIM in that it computes the transition curves for both rigid lid and free surface baroclinic experiments, agreeing with the observations for most of parameter space. The primary scientific contribution of this paper, however, is the study of hysteresis of the upper transition curve for the free-surface case. For large thermal Rossby numbers, it has been found experimentally that the flow may include baroclinic waves or not for a given set of external parameters, depending upon whether the waves were previously established before moving to that set of parameters. The calculations show that the hysteresis is due to a jump in wave amplitude when the external parameters are changed, and this jump is due to the presence of a positive feedback between the wave and mean state. That is, while it is usually considered that the waves act to stabilize the mean flow (negative feedback), there is the capability for a destabilization involving the combination of baroclinic and barotropic feedbacks. More details will be given at the review.

GEOSIM has been used for fully nonlinear simulations which have been animated on the Division's Stellar and Stardent computers. Cases have been completed for the traditional baroclinic annulus, the MSFC bottom-heated annulus, the GFFC, and for channel calculations. The most striking of these are the GFFC cases, which are simulations of Spacelab 3 experiments. These cases are with heating from below in addition to latitudinal temperature gradients, and the flow, while laminar, is quite chaotic and complex. Examples will be shown at the review.

A version of GEOSIM was used to study nonhydrostatic vertical and slantwise convection on the small scale. This work was motivated by results using the mesoscale model LAMPS which indicated that symmetric instability in the atmosphere may be quite sensitive to vertical convection from below. These results were shown at the 4th Conference on Mesoscale Processes last month.

Focus of Current Research:

GEOSIM is being used to study the phenomenon of vacillation in the baroclinic annulus. Having verified that the code predicts vacillation for the same points as the experiments, the work is aiming toward explaining the mechanics of vacillation and pointing out some of the sensitivities of the results to the numerical method. We are finding that there is a structural change associated with "amplitude vacillation", where the structural changes are in the vertical. Our results disagree with the premise of Lindzen et al. that the vacillation is due to constructive and destructive interference of neutral modes with different phase speeds.

We are continuing to study the Spacelab 3 GFFC results with horizontal temperature gradients and heating from below. GEOSIM has been used to compute a wide range of cases, and these are being compared with the observations. The computations and observations compare well, and the model is being used to extend the results beyond cases studied in the experiments and to study the mechanics and predictability of the flows.

The study of fully nonlinear baroclinic instability using the GFFC apparatus is proceeding with the numerical code. While the first instability that occurs is of planetary scale, secondary instabilities consisting of small-scale, penetrative convection occurs where cold fluid flows over a warm surface. The simultaneous modeling of the planetary scale and the convective scale is possible because of the nonhydrostatic formulation of the model. Some of these results have been animated on the Stardent computer, which shows the explosive nature of the small-scale convection.

Plans for Next Year:

We will be continuing the work in the preceding section. Our goals include a publication on each of the three paragraphs above.

The laboratory work will be revived. We have constructed a new lid for the annulus which is outfitted with thermistors. We are developing the software for an IBM PC which will allow the acquisition and recording of thermal data at the top of the flow cell. This will allow us to better study the dynamics of the flow and to compare it more quantitatively with the numerical model.

Publications:

Miller, T. L., and J. D. Fehribach, 1990: A numerical study of the onset of baroclinic instabilities in spherical geometry. Geophys. Astrophys. Fluid Dyn., 52, 25-43.

Miller, T. L., and K. A. Butler, 1990: Hysteresis and the transition between axisymmetric flow and wave flow in the baroclinic annulus. J. Atmos. Sci., accepted.

Miller, T. L., and S.-H. Chou, 1990: Numerical experiments on the interaction between vertical and slantwise convection. Fourth Conference on Mesoscale Processes, June, 1990, Boulder, CO.

Title: Synoptic/Planetary-Scale Interactions and Blocking over the North Atlantic Ocean

Investigators: Phillip J. Smith (PI)
Mary A. Uhl (Project Assistant)
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Significant Accomplishments in the Past Year:

Work was completed on the height tendency diagnoses of two extratropical cyclones that occurred upstream from the blocking event studied previously. One developed explosively over water 60 to 36 hours before the block first appeared, while the second developed explosively over the southeastern United States during the time of block formation. In both cases, both vorticity and temperature advection were consistently important forcing mechanisms. This is in contrast to the block itself, in which vorticity advection was easily the dominant forcing mechanism. Latent heat release was also significant, accounting for about 50% of the total height falls in the cyclone below 850 mb. Estimates of latent heat release were greatly enhanced by coupling parameterized estimates with values derived from GOES IR data using an algorithm developed by Marshall's F.R. Robertson.

Among the difficulties encountered in this work was the identification of an appropriate lower boundary condition for the solution of the height tendency equation. The zero value currently used tends to yield underestimates of the lower troposphere height tendencies. To address this problem a new diagnostic technique was developed in cooperation with Dr. Peter Zwack of the University of Quebec at Montreal. Based on an equation Dr. Zwack had previously developed (the Zwack-Okossi development equation), we now have a relationship that is completely consistent with the height tendency equation and provides estimates of lower boundary geostrophic vorticity or height tendencies.

Finally, comparison of the SAT and NOSAT analyses is progressing well. Basic fields from the two analyses are very similar (correlation coefficients typically greater than 0.95), while higher order derived parameters (e.g., terms in the height tendency equation) sometimes exhibit correlations less than 0.90.

Focus of Current Research and Plans for Next Year:

The present focus is on both the new diagnostic technique and the SAT/NOSAT comparisons. The former is being tested on the southeastern United States cyclone case previously mentioned and compared with the height tendency

diagnoses already completed. The latter are being examined for the blocking case described in the publications cited in this summary. In addition to obtaining statistics that will allow general comparison of the two analyses, it will be possible to determine whether conclusions about the dynamics of the block development are influenced by the analysis set used.

Publications:

1. **Refereed:**

   a. Tsou, C.-H., and P.J. Smith (1990): The Role of Synoptic/Planetary-Scale Interactions During the Development of a Blocking Anticyclone. Tellus, 42A, 174-193.

   b. _____, and _____ (1990): The Importance of Non-Quasigeostrophic Forcing During the Development of a Blocking anticyclone. Tellus, 42A, 328-342.

2. **Non-refereed:**

   Fosdick, E.K., and P.J. Smith: Latent Heating Associated With a Rapidly Developing Cyclone Over the North Atlantic Ocean. Preprints of the 12th Conference on Weather Analysis and Forecasting, October 2-6, 1989, Monterey, CA.

3. **Presented papers**

   Both papers presented at the Fifth Scientific Assembly of IAMAP, July 31 - August 12, 1989, Reading, United Kingdom.

   Smith, P.J., and C.-H. Tsou: The Importance of Non-Quasigeostrophic Forcing During the Development of a Blocking Anticyclone.

   Smith, P.J., and M.A. Uhl: A Diagnosis of a Rapidly Developing Winter Cyclone Over the North Atlantic Ocean.

4. **Theses**

   a. **M.S.**

      Fosdick, E.K.: The Role of Latent Heating in the Explosive Development of Two Extratropical Cyclones (August, 1989).

      Uhl, M.A.: Synoptic-Scale Forcing of Two Explosively Developing Cyclones (December, 1989).

   b. **Undergraduate Honors**

      Knabb, R.D.: The Role of Vorticity in an Explosively Deepening Extratropical Cyclone (May, 1990).

The Effect of Latent Heat Release on Synoptic-to-Planetary Wave Interactions and Its Implication for Satellite Observations: Theoretical Modeling

INVESTIGATORS:

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SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

As an introduction, the project objectives are:

- Develop process models to investigate the interaction of planetary and synoptic-scale waves including the effects of latent heat release (precipitation), nonlinear dynamics, physical and boundary-layer processes, and large-scale topography
- Determine the importance of latent heat release for temporal variability and time-mean behavior of planetary and synoptic-scale waves
- Compare the model results with available observations of planetary and synoptic wave variability
- Assess the implications of the results for monitoring precipitation in oceanic storm tracks by satellite observing systems.

We have utilized two different models for this project:

a. A *two-level quasi-geostrophic* model to study intraseasonal variability, anomalous circulations and the seasonal cycle. This version explicitly resolves a few planetary and synoptic waves and examines the effect of latent heat release and topography on their interaction.

b. A *10-level, multi-wave primitive equation* model to validate the two-level Q-G model and examine effects of convection, surface processes, and spherical geometry. It explicitly resolves several planetary and synoptic waves and includes specific humidity (as a predicted variable), moist convection, and large-scale precipitation.

Work with the two-level quasi-geostrophic model was performed during the first two years of the contract and described in previous annual reports. The results have been presented in three refereed publications, coauthored by Drs. Branscome and O'Brien. In the past year we have concentrated on experiments with the multi-level primitive equation model. The dynamical part of that model is similar to the spectral model used by the National Meteorological Center for medium-range forecasts. The model includes parameterizations of large-scale condensation and moist convection. To test the validity of our results regarding the influence of convective precipitation, we can use either one of two different convective schemes in the model, a Kuo convective scheme or a modified Arakawa-Schubert scheme which includes down-drafts. By choosing one or the other scheme, we can evaluate the impact of the convective parameterization on the circulation.

In the past year we performed a variety of initial-value experiments with the primitive equation model. Using initial conditions typical of climatological winter conditions, we examined the behavior of synoptic and planetary waves growing in moist and dry environments. Surface conditions were representative of a zonally averaged ocean. We found that moist convection associated with baroclinic wave development was confined to the subtropics. Its contribution to

wave energetics was fairly small, although precipitation amounts were similar to the amounts from large-scale condensation. The result was similar for either choice of convective parameterization.

Precipitation in middle and high latitudes in our experiments was dominated by large-scale condensation. Large-scale condensation had its strongest effect on the short synoptic scales (zonal wavenumber 14) and accelerated the growth and decay of these waves. Latent heating did not directly enhance growth on the planetary scale (zonal wavenumber 4), but heating within the planetary scales modestly accelerated baroclinic growth of the synoptic scales. Also, some amplification of the planetary scales occurred when latent heat was released in the synoptic-scale waves.

The large-scale condensation was generated by mid-tropospheric upward motion in synoptic-scale waves and by cooling of moist air in low-level poleward flow over a comparatively cold sea surface. Thus, sensible heat exchanges between the model atmosphere and surface were important in determining the vertical distribution of condensation within the waves. However, latent heat release in the mid-troposphere made the most direct and obvious contribution to wave growth, whereas low-level condensation generated by surface processes did not enhance wave development. The vertical distribution of latent heat release and its impact on wave growth affects observational requirements for remote sensing, esp. over ocean areas. Our results suggest that mid-tropospheric latent heat release associated with synoptic-scale uplift is the most important contributor to wave dynamics and prediction and should receive special attention in observational studies.

In addition to the aforementioned experiments, we have also investigated the effect of climate change on water vapor transport and precipitation within mid-latitude waves. Climatic states generated by two different GCM's with current and doubled amounts of CO_2 were used as initial conditions for experiments with our primitive equation model. The model was integrated over the life cycle of a transient eddy. These short-term experiments allowed us to isolate the waves and their transport and precipitation processes from the many other feedbacks present in GCM climate experiments. By changing the initial conditions, surface processes, and model resolution, we were able to assess the impact of certain processes and modeling procedures on wave evolution, water vapor transport, and precipitation. Smaller meridional temperature gradients in a doubled CO_2 climate reduced eddy energy and sensible heat transport and shifted precipitation and eddy activity poleward. In contrast, the change in water vapor transport was comparatively small due to the compensating effect of higher specific humidity in the doubled CO_2 climate. These experiments indicate which aspects of eddy activity and transport will respond to climate change. Results of this research were presented at the June 1990 Chapman Conference on the Hydrological Aspects of Global Climate Change.

FOCUS OF CURRENT RESEARCH:

As the current project draws to a close in the next few months, we will perform some final experiments and prepare manuscripts which describe final results and conclusions. We are investigating more fully the contribution of moist convection to wave dynamics and interactions. We plan to perform some experiments in which the initial conditions are more conditionally unstable than the climatological zonal mean. Unstable conditions over the oceans are most likely to occur off the eastern coasts of the Asia and North America. These experiments will allow us to further compare precipitation processes and their effect on mid-latitude wave growth.

PLANS FOR NEXT YEAR:

For the next year we propose to investigate the interactions of clouds and mid-latitude transient eddies. Recent analyses of the earth's radiation budget (e.g., Ramanathan et al., 1989: Climate and the Earth's radiation budget. *Physics Today*, 42, 22-32; Ramanathan et al., 1989: Cloud-radiative forcing and climate: Insights from the Earth Radiation Budget Experiment. *Science*, 243, 57-63) have shown that the cloudy regions of extratropical storm tracks make a significant contribution to net global cooling by clouds and are likely to be a critical factor in the

global response to greenhouse enhancement. These storm tracks are dominated by synoptic-scale transient eddies, which are easily identified in satellite photos by their distinctive cloud patterns. Understanding the interactions of clouds and large-scale motions is essential for short-term weather prediction, since clouds and precipitation are key elements of daily weather. In addition to generating clouds, mid-latitude transient eddies accomplish a substantial portion of the total atmospheric transport of heat, moisture, and angular momentum. As a result, these eddies and associated cloud patterns constitute an important component of the general circulation.

We will evaluate various methods of cloud modeling and examine cloud behavior in the context of individual synoptic-scale eddies and long-term averages. We will also examine how physical processes such as radiation, moist convection, and surface fluxes control cloud-eddy interactions in context of a multi-level primitive equation model. One objective is an understanding of the response of eddies and their cloud systems to climate change. Our study of relevant physical processes will isolate certain interactions and thus, provide a clearer understanding of cloud feedbacks that occur in complex climate models, namely general circulation models. In addition, the results of our study will identify cloud processes that require more effective and accurate observation by remote sensing techniques. Our objectives will be accomplished through a variety of experiments with an idealized primitive-equation model, the same model described above but including cloud parameterizations and radiative transfer. The model will be configured to isolate feedbacks between clouds and mid-latitude transient eddies from other dynamical processes such as tropical waves and mid-latitude stationary waves.

Our three-year study will examine cloud-eddy interactions in the context of two types of experiments: (a) "life-cycle" experiments and (b) "climatic equilibrium" experiments. The life-cycle experiments are initial value problems which examine the effect of various physical processes, modeling procedures, or global climate changes on the life history of a single baroclinic eddy. A large number of these short-term (~20 day) integrations will be performed. Following various tests of modeling procedures in the life-cycle experiments, some climatic equilibrium experiments will be performed. The equilibrium experiments will primarily investigate the response of clouds and transient eddies to changes in external forcing, such as sea surface temperatures and insolation. The model will be integrated over long periods (several hundred days) to obtain an equilibrated or statistically steady state.

PUBLICATIONS:

1. Refereed papers by Branscome and O'Brien:

1988: Modes of variability in a low-order, two-level model. Tellus, 40A, 358-374.

1989: Minimal modeling of the atmospheric general circulation. Tellus, 41A, 292-307.

1990: The effect of large-scale topography on the circulation of low-order models. To appear in Oct 1 or 15 issue of J. Atmos. Sci.

2. Manuscripts in preparation by Branscome and co-workers:

a. Determination of frictional time scales for low-order models. To be submitted to J. Atmos. Sci.

b. The impact of global climate change on water vapor transport by transient eddies. To be submitted to J. Climate.

c. The effect of latent heat release on the interactions of nonlinear baroclinic waves. To be submitted to J. Atmos. Sci.

TITLE: The Effect of Latent Heat Release on Synoptic-to-Planetary Scale Wave Interactions and Implications for Satellite Observations: Observational Study

INVESTIGATORS: Stephen J. Colucci
Timothy L. Alberta

AFFILIATION: Department of Soil, Crop and Atmospheric Sciences
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Ithaca, New York 14853

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

We have continued our diagnostic studies of observed atmospheric phenomena in which latent heat release may influence the interaction between synoptic and planetary-scale circulations. We have also extended this work to include diagnostic studies of forecasts of these interactions by the Community Climate Model (CCM) at the National Center for Atmospheric Research (NCAR).

Our previous work has identified an indirect role of latent heat release (inferred from satellite data) in one case of synoptic-planetary scale interaction studied, i.e. in the formation of a large blocking pattern following the landfall of Hurricane Juan (1985). Specifically, latent heat released in the Hurricane's rainfall modified the temperature field in such a way that 500 mb height rises forced by warm air advection and associated with the block development were larger than they would have been without the latent heat release.

The rate at which the 500 mb anticyclone in the blocking pattern intensified, in part due to the latent heat enhanced warm air advection, was significantly larger than the average intensification rate of 500 mb anticyclones in a large sample we have studied. We have termed this process rapid 500 mb anticyclogenesis, and have constructed a synoptic climatology of this phenomenon as well as of rapid 500 mb cyclogenesis. Most such anticyclones are observed north of the 500 mb westerlies and thus may be regarded as cutoff or blocking systems. Many are observed downstream of rapidly intensifying surface cyclones. In a separate case study, we have diagnosed the contributions to 500 mb height rises in one such anticyclone and found them to be due almost exclusively to warm air advection downstream of an intense oceanic surface cyclone. Since it is well known that latent heat release is an important physical process in these rapidly intensifying surface cyclones, as in hurricanes, then we hypothesize that the released heat is enhancing the warm air advection in the same way as found in the Hurricane Juan case. However, we need to diagnose this possibility with satellite data.

We have found that operational short-range forecasting models underpredict rapid 500 mb anticyclogenesis, as well as associated upstream surface cyclones. We hypothesize that misforecast latent heat release in the cyclones leads to the 500 mb anticyclone's forecast error.

The accuracy with which Atlantic Ocean surface cyclones are forecast at short and medium range by the NCAR CCM depends, in the sample studied, upon the initial conditions. Initial states with faster than normal 500 mb geostrophic westerlies over the western Atlantic Ocean are followed in time by intense and poorly predicted oceanic surface cyclones. Hemispheric forecast skill deteriorates rapidly in these cases. In one such case studied, the synoptic-planetary scale wave interactions are poorly forecast at short and medium range at 500 mb over the Atlantic Ocean. Initial states with weaker than normal westerlies over the western Atlantic are followed in time by relatively weak and better forecast oceanic surface cyclones. Hemispheric forecast skill is maintained in these cases through the medium range, on average, and skillful 30-day forecasts was occasionally noted. One such diagnosed case revealed that synoptic-to-planetary scale interaction at 500 mb over the Atlantic Ocean was well-forecast through the medium range. It is hypothesized that skillful extended-range forecasts of surface cyclones and that this may in turn depend upon the initial conditions. Forecasts of intense oceanic surface cyclones for which latent heat release is known to be important could potentially be improved by incorporating satellite information into the initial conditions.

FOCUS OF CURRENT RESEARCH:

We have been exploring alternative methods to facilitate the prediction of rapidly intensifying surface cyclones. Recognizing that synoptic-scale systems, such as these cyclones, are less predictable at medium range and beyond than are planetary-scale circulations, we propose that the planetary-scale environment for explosive cyclogenesis could be better predicted than the cyclones themselves. We have therefore constructed a planetary-scale climatology of explosive cyclogenesis by compositing together filtered 500 mb height fields (retaining planetary waves only) corresponding to a large sample of rapidly intensifying surface cyclones, stratified geographically and according to the direction of 500 mb geostrophic flow (southwesterly, northwesterly or westerly) over the cyclone center. The composites are calculated from five days preceding to five days following each rapid cyclogenesis event, and have climatology subtracted so that the evolution of planetary-scale anomalies before and after cyclogenesis can be followed. Whether the anomalies are distinct from background variability and thus provide predictive value is now being evaluated.

Following explosive cyclogenesis over which the filtered 500 mb flow is southwesterly, there appear in the composites large positive 500 mb height anomalies downstream. In some cases, these anomalies are associated with blocking patterns. Whether the objectively-defined blocking patterns in the data set are preceded by upstream intense surface cyclone activity is being investigated.

Finally, the contribution of synoptic-scale processes, notably warm air advection, to planetary-scale height rises during a block formation following an explosive cyclogenesis event is being diagnosed. We hope to eventually evaluate the impact of satellite derived latent heat release upon the warm air advection in this case.

PLANS FOR NEXT YEAR:

We wish to explore the possibility that incorporating satellite-derived latent heat release into the initial fields of an extended-range forecast may improve the forecast accuracy. To accomplish this, we plan to perform forecast experiments with the NCAR CCM. In these experiments, the CCM initial latent heating (forecast from other variables) will be replaced with satellite-derived estimates of the heating, using Dr. Pete Robertson's precipitation algorithm. The cases to be selected will feature forecasts of explosive surface cyclogenesis at different times after the initial time. The purpose of these experiments will be to assess the impact of the satellite-modified initial conditions upon forecasts of cyclones early in the forecast cycle, and upon forecasts of the background planetary-scale environment preceding later cyclones. The initial time will be moved forward in a set of experiments designed to assess the utility of updating an extended-range forecast cycle with satellite information.

MANUSCRIPTS PREPARED IN THE PAST YEAR:

Alberta, T.L., S.J. Colucci and J.C. Davenport: Rapid 500 mb cyclogenesis and anticyclogensis. (submitted to Monthly Weather Review).

Colucci, S.J. and D.P. Baumhefner: Initial weather regimes as predictors of numerical long-range forecast accuracy. (submitted to the Journal of the Atmospheric Sciences).

Title: **Potential Vorticity Index**

Investigators:

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I. Significant Accomplishments in the Past Year

1. Data handling: a synopsis

(1) Dr. Weng attended the NASA Climate Data System (NCDS) Workshop, held at Goddard Space Flight Center, NASA, in October 1989;

(2) Using knowledge gained at that workshop we attempted to use the reanalyzed ECMWF FGGE data through NCDS instead of the original ECMWF FGGE data we used in the past for the SOP periods.

(3) After unpacking the new data we discovered systematic departures from the old data set which caused oscillations in our time series. By February 1990 we reverted to the original ECMWF FGGE data set.

2. Presentation at a meeting

We presented a paper at the XV General Assembly of the European Geophysical Society (April 1990).

3. Publication

We are writing-up a paper to be submitted to Monthly Weather Review in the summer 1990.

4. Research accomplishments

(1) Motivation

Our work was motivated by the success of "Isentropic Potential Vorticity (IPV) thinking". Using these concepts, we propose to describe dynamical processes as well as interactions between atmospheric action centers (Hoskins et al., 1985; Haynes and McIntyre, 1987)

(2) Main themes of research

Using standard data analysis techniques, we propose to explore the links between:

a. disturbance growth and quasi-geostrophic PV gradients;

b. appearance and disappearance of cutoff lows and blocking highs and their relation to a zonal index (properly defined in terms of PV);

c. teleconnections between different flow patterns and their relation to the zonal index.

(3) Data analyses

The FGGE Level IIIb analyses made by ECMWF for the winter period of Dec 1, 1978 – Feb 28, 1979 (twice/day) are used for this study. All data at $1.875° \times 1.875°$ latitude -longitude grid points between 0 – 90N are used for IPV at $300K$ and geopotential height at $500mb$. A PV index is defined by zonally averaged PV gradient between two latitude belts $60 - 71.25N$ and $33.75 - 41.25N$. We study the correlation between this index and eddy activity in both frequency and time domains.

(4) Main results

a. The PV index and the eddy index correlate better than a zonal index (defined by zonal wind) and the eddy index. In the frequency domain there are three frequencies (.03, .07 and .17 cpd (cycle per day) corresponding to periods of 33, 14 and 6 days) at which the PV index and the eddy index exhibit local maxima. The high correlation found at periods of 33 days is mainly due to eddy activity at high latitudes while the local correlation maxima found at the shorter periods are mainly due mid-latitude eddy activity.

b. The correlation between the PV index and the geopotential height anomaly at $500mb$, at each grid point in the Northern Hemisphere, shows the existence of most of the teleconnection patterns summarized by Wallace and Gutzler (1981): the North Atlantic Oscillation, the North Pacific Oscillation, and the Pacific/North American patterns. The existence and the evolution of these patterns are seen from daily $500mb$ maps during this period. Each pattern has two extreme phases, corresponding to high and low PV index periods, respectively, with a few days' lag. The area over Scandinavia and the Norwegian Sea seems to be a key area which affects global flow changes. The composite maps show that, in general, high and low index periods correspond to "wavy" and "zonal" flow in mid-latitudes, respectively, especially over Europe.

c. Our results show that the IPV analysis can be a very useful and powerful tool when used to understand the dynamics of several large scale atmospheric systems. Although the data are limited to only one winter, and it is difficult to assess the statistical significance of the correlation coefficients presented here, the results are encouraging from physical viewpoint.

II. Focus of Current Research and Plans for Next Year

1. Complete the paper pertaining PV index vacillation in Northern Hemisphere, while trying to understand more about the phenomena physically.

2. Perform EOF analyses of high- and mid-latitude geopotential height anomalies and relate the results with the PV index. The purpose of it is to find possible relationship between blocking and cyclogenesis at different locations with the variation of the PV index.

3. Start a similar research for the FGGE winter in the Southern Hemisphere. The comparison between the results for two hemispheres is very useful for understanding the effect of topography in the Northern Hemisphere.

III. Papers and Presentations Supported by NASA in the Past Year

1. Weng, H.-Y., 1990: The effects of oppositely sloping boundaries with Ekman dissipation in a nonlinear baroclinic system. *Quart. J. Roy. Meteor. Soc.*, **116**, 1 – 29.

2. Weng, H.-Y. and A. Barcilon, 1990: Potential vorticity index and its relation to blocking and cyclogenesis. *XV General Assembly of European Geophysical Society, 23 – 27 April, 1990.*

3. Weng, H.-Y. and A. Barcilon, 1990: Potential vorticity index vacillation. Part I: its relation to teleconnection. To be submitted to *Mon. Wea. Rev.* in August.

Title: Use of Satellite Data and Modeling to Assess the Influence of Stratospheric Processes on the Troposphere

Principal Investigator:

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Significant Accomplishments in the Past Year (1989-1990)

1. Barotropic instability of realistic zonally varying flows in the stratosphere: a possible mechanism for the origin of free planetary waves observed in satellite data.

A variety of waves exist in the stratosphere whose origin and mechanisms governing their life cycles are poorly understood. The difficulty stems, in part, from the fact that many interrelated nonlinear physical and dynamical processes are involved in their evolution. To shed further light on the possible origin of such features as the "two-day" mesospheric wave and the short-period, long-lived disturbances observed in satellite data in the polar winter stratosphere, we have examined the stability of *time dependent zonally varying flow* using nondivergent barotropic models on a sphere. The basic states used in the models were based on idealized flows, and on realistic flows that were constructed from satellite data. Details concerning this work can be found in Manney, Nathan and Stanford (1989) and Manney and Nathan (1990).

Briefly, we have shown that for a basic state consisting of a realistic zonal jet and a travelling wave, coherent disturbances characterized by a multimode zonal wave spectrum emerge which move with the basic state wave. These disturbances may be related to the quasi-nondispersive features observed in satellite data in the polar winter stratosphere (Lait and Stanford, 1988; *JAS*). We also have examined the stability of a basic state that is composed of a westward-moving wave and a zonal mean jet. The sensitivity of the flow stability to the strength and structure of the zonal jet was emphasized. We found that for a basic state resembling the observed "two-day" wave, inclusion of an easterly (summer) jet in the basic state has a srong stabilizing influence. When a *strong* easterly jet is included in the basic state, unstable disturbances occur that have structures similar to waves observed concurrently with the two-day wave. Evidence was also presented showing a seasonal dependence in the stability of several westward moving basic state waves.

2. Stability of simple models of the earth system: interactions among radiation, photochemistry, and dynamics.

Over the years, numerous studies have examined the stability of atmospheric flows to planetary and synoptic-scale perturbations. Nevertheless, our understanding of the mechanism(s) responsible for the birth, evolution, and eventual demise of such waves is clearly inadaquate. To provide a better understanding of how ozone can affect planetary waves, Nathan (1989) examined analytically the linear stability of free planetary waves in the presence of radiative-photochemical feedbacks in a continuously stratified, extratropical baroclinic model of the atmosphere. The flow was described by *coupled* equations for the quasigeostrophic potential vorticity and ozone volume mixing ratio. It was shown that radiative-photochemical feedbacks can destabilize free planetary waves. The expression for the growth rate was obtained in terms of the vertically averaged wave

activity, and depends on three distinct processes: i) meridional advection of basic state ozone, ii) vertical advection of basic state ozone, and iii) photochemically accelerated cooling. For waves whose peak amplitudes are in the lower stratosphere, vertical ozone advection dominates and is destabilizing. Extensions of this work to climatological and realistic instantaneous basic state wind, temperature, and ozone profiles has been initiated.

Focus of Current Research

Our current research is focused on the following problems:

1. *Examination of the effects of ozone heating and Newtonian cooling on the linear stability of transient planetary waves.* A finite difference numerical model was developed in which the basic state wind, temperature, and ozone distributions were constructed using ground-based and satellite data. Preliminary results indicate that ozone dynamics interaction may play a more important role in the stability and maintenance of planetary waves than previouly thought, particuarly in summer when the mean solar zenith angle is smallest and thus ozone heating largest.
2. *Examination of the finite amplitude interactions among radiation, ozone, and dynamics.* Self-consistent, coupled equations governing the weakly nonlinear interactions between the ozone and streamfunction fields has been derived. These equations are currently being analyzed to provide a better understanding of wave-mean flow interactions and ozone transport in a continuously stratified model of the troposphere-stratosphere coupled system.

Plans for Next Year

A new proposal has been submitted to NASA. This proposal forms a logical and significant extension of work carried out by the PI and his graduate students under the current NASA grant, which is scheduled to end in January 1991. The goal is to carry out a comprehensive, multifaceted analysis of the *combined* physical processes that generate, maintain, and damp planetary-scale waves at middle latitudes. Attention will be focused on those components of the earth system that combine the diabatic processes generated by internal radiative-photochemical feedbacks and external periodic (seasonal) forcing with the large-scale circulation of the atmosphere. To carry out the research, analytical and numerical models of the troposphere-stratosphere coupled system in beta-plane and spherical geometries will be used in conjunction with ground-based and satellite data.

Refereed Publications (1989-1990)

1. Nathan, T. R., 1989: On the role of dissipation in the finite amplitude interactions between forced and free baroclinic waves. *Geophys. Astro. Fluid Dyn.*, **45**, 17 pgs.
2. Manney, G. L., T. R. Nathan, and J. L. Stanford, 1989: Barotropic instability of basic states with a realistic jet and a wave. *J. Atmos. Sci.*, **46**, 13 pgs..
3. Nathan, T. R., 1989: On the role of ozone in the stability of Rossby normal modes. *J. Atmos. Sci.*, **46**, 6 pgs.
4. Manney, G. L., and T. R. Nathan, 1990: Barotropic instability of westward-moving waves in realistic stratospheric zonal flows. *J. Atmos. Sci.*, **47**, 19 pgs.
5. Howell, P., and T. R. Nathan, 1990: Barotropic instability of zonally varying flow forced by multimode topography. *Dyn. Atmos. Oceans.* (in press)
6. Nathan, T. R., and L. Li, 1990: Effects of ozone and Newtonian cooling on the linear stability of transient planetary waves. (To be submitted to *J. Atmos Sci.*)

Additional Personnel Involved in the Project

Dr. Gloria Manney (Completed Ph.D. in 1988. Dr. Manney is currently a National Research Council Post Doctorate Fellow at the Jet Propulsion Laboratory.)

Mr. Paul Howell (Completed M.S. in 1989. Thesis title: A simple model of barotropic instability of flow forced by multimode topography.)

Ms. Cathy Hamann (M.S. expected in 1990. Thesis title: Linear and nonlinear stability of zonally varying flow.)

Mr. Long Li (M.S. expected in 1990. Thesis title: Effects of ozone heating and Newtonian cooling on the stability of transient planetary waves.)

AGENDA

NASA/MSFC GLOBAL SCALE ATMOSPHERIC PROCESSES RESEARCH PROGRAM

FY90 REVIEW

ROOM 107, BUILDING 4481, MSFC

Monday, August 20, 1990

8:30	Coffee and doughnuts	
9:00	*Welcome & Introduction*	Einar Tandberg-Hanssen Fred Leslie, MSFC
9:15	*HQ Program Overview*	John Theon, Robert Schiffer, Ramesh Kakar, NASA HQ
9:30	*Comparison of SSM/I Measurements to Numerically-Simulated Cloud and Precipitation During ERICA*	F. R. Robertson, MSFC
10:00	*Observation Simulation Experiments With Regional Prediction Models*	Mike Kalb, USRA
10:30	*South Pacific Convergence Zone and Global-Scale Circulations*	Dayton Vincent, Purdue U.
11:00	*Research On Diabatic Initialization*	Akira Kasahara, NCAR
11:30	*Planetary Circulations in the Presence of Transient and Self-Induced Heating*	Murry Salby, U. of Colorado
12:00	LUNCH	
1:00	*Stratiform Clouds and Their Interaction With Atmospheric Motion*	John Clark, PSU
1:30	*Global Variability of Water Vapor and Condensate From SSM/I*	F. R. Robertson, MSFC
2:00	*Global Scale, Intraseasonal Fluctuations of Diabatic Forcing of the Atmosphere*	John Christy, UAH
2:30	BREAK	
2:45	*Tropical Pacific Moisture Variability*	James McGuirk, TAMU
3:15	*Nonlinear Dynamics of Global Atmospheric and Earth System Processes*	Barry Saltzman, Yale U.
3:45	*Laboratory and Theoretical Models Of Planetary-Scale Instabilities and Waves*	John Hart, U. of Colorado
4:15	*Theoretical and Experimental Studies of Baroclinic Processes*	Tim Miller, MSFC

4:45	ADJOURN	
6:30	DINNER @ FOGCUTTER Restaurant, 3805 University Drive	

Tuesday, August 21, 1990

8:30	Coffee and doughnuts	
9:30	*Synoptic/Planetary Scale Interactions and Blocking Over The North Atlantic Ocean*	Phil Smith, Purdue U.
10:00	*The Effect Of Latent Heat Release On Synoptic-To-Planetary Wave Interactions And Its Implication For Satellite Observations: Theoretical Modeling*	Lee Branscome, Env. Dyn. Res.
10:30	*The Effect Of Latent Heat Release On Synoptic-To-Planetary Scale Wave Interactions and Implications for Satellite Observations: Observational Study*	Stephen Colucci, Cornell U.
11:00	*Potential Vorticity Index*	Albert Barcilon, Hengyi Weng, FSU
11:30	*Use of Satellite Data and Modeling to Assess The Influence Of Stratospheric Processes On The Troposphere*	Terry Nathan U. of Calif., Davis
12:00	*Global Temperature Monitoring With MSU*	Roy Spencer, MSFC
12:30	ADJOURN	

NASA

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CP-3093		

4. Title and Subtitle
NASA/MSFC FY90 Global Scale Atmospheric Processes Research Program Review

5. Report Date
October 1990

6. Performing Organization Code

7. Author(s)
F. W. Leslie, Editor

8. Performing Organization Report No.
ES42

10. Work Unit No.
M-651

9. Performing Organization Name and Address
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

11. Contract or Grant No.

13. Type of Report and Period Covered
Conference Publication

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared by Earth Science & Applications Divison, Space Science Laboratory, Science & Engineering Directorate.
Proceedings of a conference held at Huntsville, Alabama, August 20-21, 1990.

16. Abstract

This document describes the research supported by NASA's Global Atmospheric Processes Research Program at the Marshall Space Flight Center. There has been much interest recently in environmental issues such as the ozone hole, the global warming of the atmosphere, etc. Debate about the magnitude of these environmental changes continues. One problem is that measurements of the atmosphere are concentrated near large cities or airports of which virtually all are located on land representing only a small part of the Earth's surface. One way to gain more understanding of the atmosphere is to make measurements on a global scale from space. One of NASA's new initiatives is the Earth Observation System, a series of new sensors to measure globally atmospheric parameters such as temperature, moisture, wind, lightning, etc. Analysis of satellite data by developing algorithms to interpret the radiance information improves our understanding and also defines requirements for these new sensors. One measure of our knowledge of the atmosphere lies in our ability to predict its behavior. In order to predict future states of the atmosphere, one must know not only the current state but also the physics which govern change. Use of numerical and experimental models provides a better understanding of these processes. This work describes these efforts in the context of satellite data analysis and fundamental studies of atmospheric dynamics which examine selected processes important to the global circulation.

17. Key Words (Suggested by Author(s))	18. Distribution Statement		
Atmospheric Remote Sensing, Atmospheric Science, Meteorology, Numerical Weather Analysis and Prediction, Satellite Data Analysis	Unclassified---Unlimited Subject Category: 47		
19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of pages**	**22. Price**
Unclassified	Unclassified	68	A04

NASA FORM 1626 OCT 86

For sale by the National Technical Information Service, Springfield, VA 22161-2171

NASA-Langley, 1990